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VOL. XLI

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VOL. XLI

H. L. LYON, *Editor*

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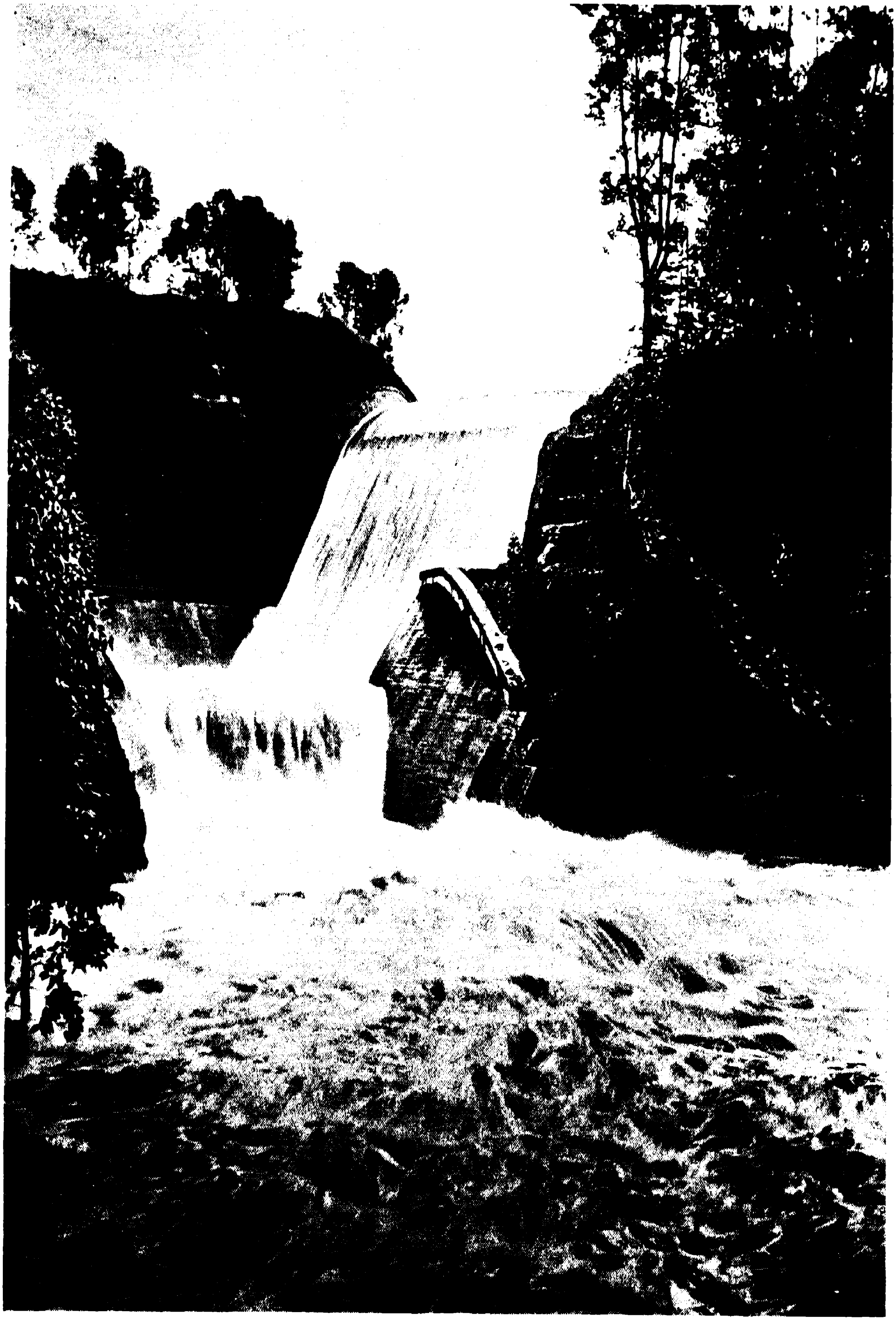
THIRD QUARTER



Spillway of the Wahiawa Reservoir, largest reservoir in the Territory of Hawaii and chief source of irrigation water for the Waialua Agricultural Company, Ltd. Courtesy of A. A. Wilson.

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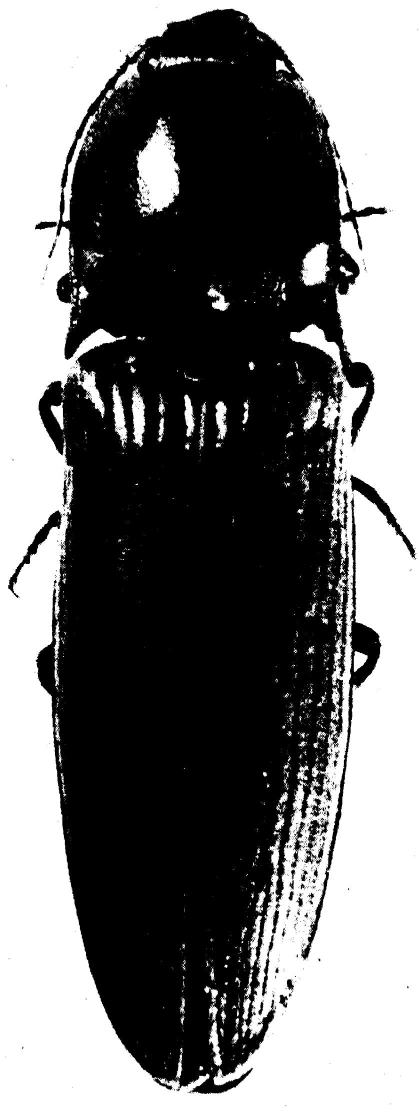


Female adult of *Pyrophorus bellamyi* Van Zwal., a click beetle of recent introduction, whose wireworm larva is expected to aid in the control of Anomala and Adoretus grubs.

THE HAWAIIAN PLANTERS' RECORD

Vol. XLI FIRST QUARTER, 1937 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

The Effect of Sunlight on the Utilization of Nitrogen and Potash by H 109 Cane:

Another cane growth study has contributed further evidence which indicates that under conditions of reduced sunlight, sugar cane may not be able to utilize effectively the larger applications of nitrogen and potash fertilizers which are sometimes supplied in an effort to compensate for certain unfavorable growing conditions.

Notes on Sugar Cane in West Africa:

The important sugar cane pests are quite different in West Africa from those affecting the crop in Hawaii, but a few wide-spread, minor insects are common to both regions. Relatives of our Anomala and Adoretus occur (though not as pests of cane), but nothing encourages the hope that effective parasites of their grub stages are obtainable there.

Yams:

A second article dealing with a food crop of considerable economic importance is presented as a sequel to that appearing in the previous volume of the *Record*.

Evaluation of Nitrogen in Molasses:

Further studies concerned with the value of nitrogen in molasses as a partial substitute for commercial nitrogen fertilizer, verify our previous findings and indicate quite definitely that most likely it will not be economical to use this mill by-product for the nitrogen which it carries.

Anomala Studies:

A correlation apparently exists between a soil's susceptibility to Anomala infestation and the figure obtained by dividing the ignition loss of the soil by its moisture equivalent. The lethal point for Anomala eggs with respect to soil moisture (a factor intimately associated with the ignition loss-moisture equivalent correlation) was found to be a very critical one, lying somewhere between 98.7 and 97.9 per cent relative humidity. Miscellaneous life history data are discussed.

The Synthesis of Sucrose by Excised Blades of Sugar Cane:

Excised leaf blades of the sugar cane plant can manufacture cane sugar in the dark when supplied with the simple sugars, glucose and fructose.

The Availability of the Principal Nutrients in a Soil During the Crop-Growth Period:

Both the natural and the imposed variations in the supply of available nutrients which have occurred in a soil supporting a normal crop throughout the entire period of its growth have been measured and are recorded especially for the benefit of those who are taking soil samples and interpreting the results of their soil analyses in terms of the principal fertilizer requirements for their sugar cane crop.

West African Notes:

The comparatively primitive agriculture of West Africa is so different from that of more advanced communities that its problems are of interest, even if offering few lessons to a more highly developed system. In spite of its crudity, the native agriculture suffices for the conditions under which millions of Africans live; that it can adapt itself to the needs of world commerce is shown by the existence of an enormous cocoa industry in the Gold Coast, which is essentially native in character. Natural advantages enable the West Coast to maintain its preeminence in certain products necessary to the white man, notably palm oil.

West Africa is the native home of numerous kinds of fruit flies, and is a rich field from which to obtain parasites useful in reducing the ravages of the Mediterranean fruit fly.

Cane Growth Studies

THE EFFECT OF SUNLIGHT ON THE UTILIZATION OF NITROGEN AND POTASH BY H 109 CANE

By R. J. Borden

On some of the sugar cane lands in these Islands the preponderance of cloudy days over sunny days is a matter of record and yet we do succeed in growing some good crops under such conditions. The results, however, are not always what we want them to be, nor are they seldom the same, even though we may have made no changes in the field practices for such lands. It is not altogether unlikely that the reason the results are dissimilar is because the weather conditions for successive crops are scarcely apt to be alike; hence, because sunlight is such a dominating weather factor, we are all interested in knowing more of its effects and influence on the other growth factors over which we do have more control.

In a previous study* concerned with climatic conditions, we found that cane which was grown under less favorable climatic influences (chiefly reduced sunlight) was unable to utilize our liberal applications of fertilizer. These liberal applications produced a gain over only one-fourth as much fertilizer, of 140 per cent on POJ 2878 cane yields without changing its quality ratio (8.3) when grown under the favorable Makiki climate, but under the less favorable (cloudy) Manoa conditions, this gain was only 40 per cent and the quality ratio accompanying this 40 per cent gain was increased from 8.7 to 12.5.

The present study (Project A-105 No. 81) was aimed to secure further information on the relationship between sunlight and two plant foods, nitrogen and potash, which we are sometimes apt to be quite liberal with, in our efforts to secure still better yields.

A well-mixed Manoa soil, low in both available nitrogen and potash, was used. It was potted in Mitscherlich pots and two uniform pregerminated shoots of H 109 cane planted therein. Ample phosphate fertilizer was furnished, and different amounts of nitrogen and of potash were provided—nitrogen fertilizer at the rate of 0, 150, 225 and 300 pounds per acre, and potash fertilizer at the rate of 0, 200, 300 and 400 pounds per acre. (Potash at 400 pounds per acre was supplied for all pots in the N series, and nitrogen at 300 pounds per acre was given to the pots in the potash series.) All treatments were in triplicate except the checks (no N and no K_2O) which were in duplicate. Three series were provided: one of these was grown continuously in full sunlight; a second series received direct sunlight from sunrise to mid-day only, while the third series was exposed to the direct sunlight from mid-day until sunset only. Thus we attempted to differentiate between the effect of (1) full sunlight vs. reduced sunlight, and (2) morning and afternoon direct light exposure, on the effective utilization of nitrogen and potash as measured by the relative amounts of dry matter produced from the initial applications that were supplied. The results are summarized in the following table and a discussion of the data follows:

*Borden, R. J., 1936. Cane Growth Studies—The Dominating Effect of Climate. *The Hawaiian Planters' Record*, 40:143-156.

EFFECT OF LIGHT ON THE UTILIZATION OF NITROGEN AND POTASH BY H 109 CANE

Differential Fertilizer Treatment (Rate per Acre)	Dry Yields (grams) In Full Sunlight	In Direct A. M. Sunlight	In Direct P. M. Sunlight	Per Cent Moisture in Cane Harvested Full Sun	A. M. Sun	P. M. Sun
No N.........	6.8± .6	5.4±1.5	6.6± .2	63.0	61.2	55.7
150 ℔ N.	82.3±3.1	76.1±1.9	74.4±2.5	66.2	70.1	69.7
225 ℔ N.	128.5±5.3	109.5±2.3	111.7±3.5	69.8	71.6	72.8
300 ℔ N.	173.1±2.2	134.0± .5	135.5±3.5	69.4	72.9	72.8
No K_2O	107.3±1.5	100.3±1.6	90.8±2.9	64.7	67.4	70.1
200 ℔ K_2O ...	144.9±1.4	122.9±5.8*	133.2±2.9*	68.9	71.8	70.1
300 ℔ K_2O ...	147.9±1.4	122.9±5.4	137.3±3.4	68.8	73.0	72.9
400 ℔ K_2O ...	173.1±2.2	134.0± .5	135.5±3.5	69.4	72.9	72.8

In view of the fact that all plants had stopped growing and showed definite symptoms of acute nitrogen deficiency when they were harvested at the age of four months, we feel justified in assuming that any further increase in weight that might have taken place would have been so small that it would have had little or no effect on our interpretation of the data which we obtained. Hence we offer the following discussion:

Differences between the morning sun and the afternoon sun were not demonstrated in the final results, although during the progress of the test, our observations had indicated that more growth was being made by the plants which were receiving the afternoon sun.

Dry weights were greater from cane grown in full sunlight, although here too our observations had indicated that stalk and leaf elongation were better in the afternoon sunlight series.

When no nitrogen was supplied all growth was very poor and there were no apparent differences in dry weights secured. When a small application of nitrogen (150 pounds per acre) was furnished, a gain of 11 times the dry-weight-without-nitrogen was obtained in both the full-sunlight series and in the reduced-sunlight series (A. M. and P. M. series averaged); however, a second similar 150 pounds per acre increment of nitrogen produced 13 and 10 times the dry-weight-without-nitrogen respectively for the full-sunlight and reduced-sunlight series, thus indicating at least that the plants grown in reduced light conditions were not able to utilize the heavier applications of nitrogen as effectively as they might have if more sunlight had been available.

This apparent inability of the plants grown under a reduced amount of light to effectively utilize the heavier applications of plant food is even more clearly shown from the results of the potash series. The first 200 pounds per acre potash increment gave very similar gains in dry weight (35 and 34 per cent respectively) for both the full-sunlight and the partial-sunlight series, but gains for potash stopped with this 200-pound application when the cane was grown under reduced light, while the plants that were grown in full sunlight gave a 20 per cent further increase in yield for a second 200-pound potash increment.

* Gains above this are not significant in this sunlight series.

Some very interesting moisture relationships are indicated. Disregarding the plants which received no nitrogen because they were barely alive at the time of harvest, it is apparent from the percentage moisture figures that the plants grown in full sunlight were less succulent than either of the series grown under reduced light. These same figures also show that the percentage of moisture in the plants at harvest was influenced by the fertilization they had received, being higher in the cane which had received the larger amounts of nitrogen and of potash than in the plants which had been given the minimum application.

From these results it may be postulated that a large part of the reason for poor juices in cane from areas that have inferior light conditions is due to the higher moisture content of such cane, and that since the moisture content is greater when liberal amounts of nitrogen and potash are furnished, better juices might be secured if we were not too liberal with these plant foods under such conditions. Furthermore, inasmuch as it is indicated that the "law of diminishing returns" is effective on cane yields sooner with lower amounts of potash and nitrogen used under reduced light conditions, it would appear that actual economies may be secured through adjustments of fertilizer applications with respect to the expected and prevalent sunlight conditions that will be likely to affect each crop. Apparently it would be a fallacy to expect that better results would be secured from lands that are subject to continued periods of overcast or cloudy weather, by boosting the nitrogen and potash applications in an attempt to compensate for the shortage of sunlight.

Notes on Sugar Cane in West Africa

By R. H. Van Zwaluwenburg

While in West Africa from November 9, 1935, to July 28, 1936, the writer had several opportunities to make observations on sugar cane. West of the Belgian Congo there is no commercial sugar industry. In the Congo there is said to be a plantation between Matadi and Leopoldville, but lack of time prevented a visit there. In the next colony to the south, Angola (Portuguese West Africa), there are seven commercial plantations; observations made on one of them, in June, have been placed on record in the Station files.

A noble cane, greenish in color, is common in dooryard plantings in Sierra Leone and Nigeria; it is grown for chewing, and is usually on sale in the native markets. Its habit of growth suggests Yellow Caledonia, a variety which it definitely is not. What is apparently the same variety was seen also in Liberia, Ivory Coast, and Gold Coast. In the French Cameroons apparently the same cane occurs, as well as a reddish variety. Nowhere are varietal names in use; all are simply "sugar cane".

Natal Uba and POJ 2878 are the principal varieties grown commercially in Angola.

Diseases

Only in Angola were definite disease symptoms seen on sugar cane. At Catumbela, near Lobito, typical mosaic symptoms were observed on large areas of Uba. On the same plantation were numerous areas of growth failure, some of considerable extent due, according to the plantation chemist, to heavy salt concentrations in the low flats near the sea, on which the cane grows.

Pests

Birds:

The most conspicuous pest of cane in Sierra Leone is the "village weaver" or "palm" bird (*Ploceus cucullatus cucullatus*) which strips the leaves of sugar cane, bananas and palms with which to weave its hanging nests. The nests are placed preferably on the tips of slender branches and twigs, but since the bird is gregarious and usually crowds a large number of nests into a single tree, even when others are available nearby, many individuals are forced to build their nests on comparatively thick branches where eggs and young are probably accessible to marauding rats. The village weaver is about the size of our mynah, or slightly smaller, its black plumage conspicuously marked with bright yellowish patches on the wings. It was observed also in Liberia, Ivory Coast, Gold Coast, and Nigeria, while nests of a similar, but perhaps different species, were seen in the Cameroons. A second species, *P. castaneofuscus* Less., also occurs in Sierra Leone, but is said not to be a pest. The manner in which *cucullatus* gathers cane leaves is interesting: after snipping the leaf blade at the base to about the midrib, it flies off, tearing the leaf longitudinally until it finally tears loose at the tip. The damage incurred is often severe; I have seen large Raphia palm trees completely defoliated by it, with little left but bare midribs.

Homoptera:

The commonest and most widespread insect on sugar cane in Sierra Leone was the cercopid *Locris maculata* Fab., which feeds also upon corn and grasses in general. It occurs also in Gold Coast, Nigeria, and French Cameroons. Ernest Hargreaves, the entomologist at Njala, Sierra Leone, knows of no parasites of this insect in his region.

Mr. Hargreaves in his very complete list of Sierra Leone economic insects, includes the following additional homoptera as attacking sugar cane:

Family		Additional hosts
Derbidae	*Diostrombus dilatata West.*	Banana, coconut, oil palms.
Derbidae	*Proutista fritillaris Boh.*	Coconut, oil and *Sabal blackburniana* palms, guava, grasses.
Lophopidae	*Elasmoscelis trimaculata Wlk.*	Grasses.

In addition, Mr. Hargreaves has taken, on sugar cane at Njala, a cercopid (probably *Poöphilus adustus* [Wlk.], an undetermined lophopid (*Lophops servillei* [Spin.] ?), and a scolytid beetle.

At Catumbela, Angola, a pink mealybug (presumably *Trionymus sacchari* Zehnt.) was widespread on sugar cane, with a dipterous maggot predaceous upon it. A single colony of what appears to be *T. boninsis* Kuwana (the gray mealybug) was seen on the same plantation; the same insect was common on cane at Njala, Sierra Leone.

A small blackish lophopid (*Elasmoscelis cimicoides* Spin.) could be found in small numbers throughout the Catumbela plantation.

Lepidoptera:

Mothborers, probably most of them, if not all, pyralids, occur all the way from Sierra Leone to Angola, and although their damage does not appear comparable to hat of Diatraea in the American tropics, in commercial plantings, such as those at Catumbela, their ravages are something to be reckoned with. Lack of time and naterial prevented the rearing of adult specimens, but in Nigeria the sugar cane orer, according to F. D. Golding, the entomologist at Ibadan, is a species of Seamia.

Spodoptera mauritia Boisd., known to Hawaii as the nutgrass armyworm, ocurs from Sierra Leone eastward, at least into Nigeria. At Ibadan, a severe outreak of this species occurred in May, the first in that district since 1921. Breeding n enormous numbers on grass, it migrated to corn used as an indicator crop in ferilizer tests, practically ruining it. Examination of over 100 larvae failed to reveal he presence of either external or internal parasites. In Sierra Leone Mr. Harreaves records *mauritia* as attacking Sabal palm foliage.

Coleoptera:

A small rutelid beetle was taken on cane in Angola, but whether or not it actually ttacks that plant is uncertain.

Anomala and related genera of beetles are widespread in West Africa, and their depredations on avocado and coffee, the favorite food plants of the adult, are occasionally severe. Scoliid wasps which might attack the grubs of this group are few in species and in numbers, and no larval parasites of the beetles are known to the entomologists with whom contact was made.

Following is a list of West African rutelid beetles compiled from records made available by Messrs. Hargreaves and Golding:

Species	Occurrence	Adult feeding plants
Adorctus mameratus Hope	Nigeria	
Adorctus hirtellus Cast.	Nigeria	Young cacao; Cola.
Adorctus similis Bend.	Sierra Leone	Cashew
Anomala chalcophora var. minor Ohs.	Sierra Leone	Avocado; *Cola nitida;* guava.
Anomala circumscriptus Hope	Nigeria	
Anomala denuda Arrow	Nigeria; Sierra Leone	Coffee; larvae in soil (about young cacao trees).
Anomala flaveola Burm.	Nigeria	
Anomala hygina Ohs.	Sierra Leone	
Anomala mixta Fab.	Nigeria	
Anomala olivacea Gyll.	Sierra Leone	
Anomala ruginosa Ohs.	Nigeria	
Anomala stigmaticollis Frm.	Sierra Leone	
Anomala sp.	Nigeria	
Chaetadoretus setipennis Ohs.	Sierra Leone	Avocado; guava; rose.
Popillia obliterata Gyll.	Sierra Leone	Rose
Popillia viridissima Blanch.	Sierra Leone	Bauhinia

In December, *Anomala denuda* was the common beetle at Njala, Sierra Leone, feeding on coffee foliage at night.

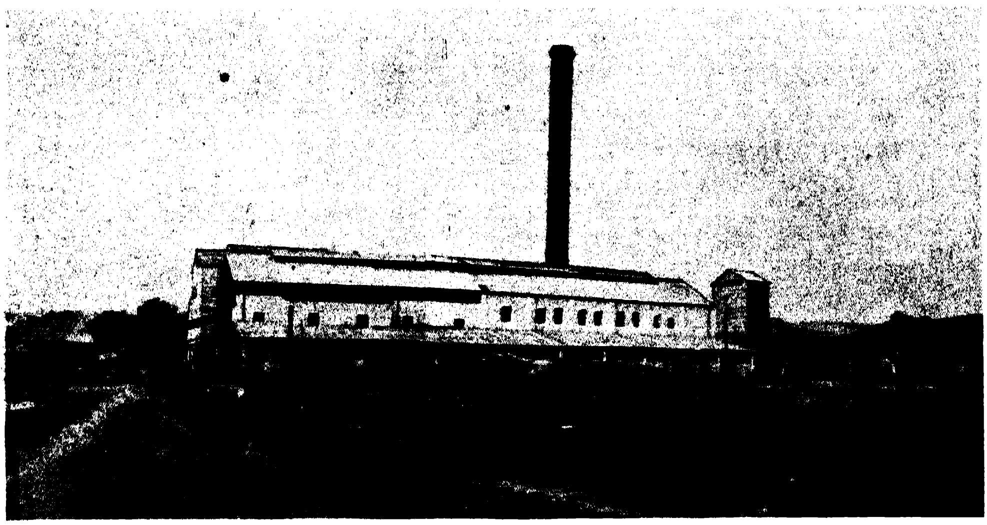


Fig. 1. Sugar factory and distillery, Angola (Portuguese West Africa).

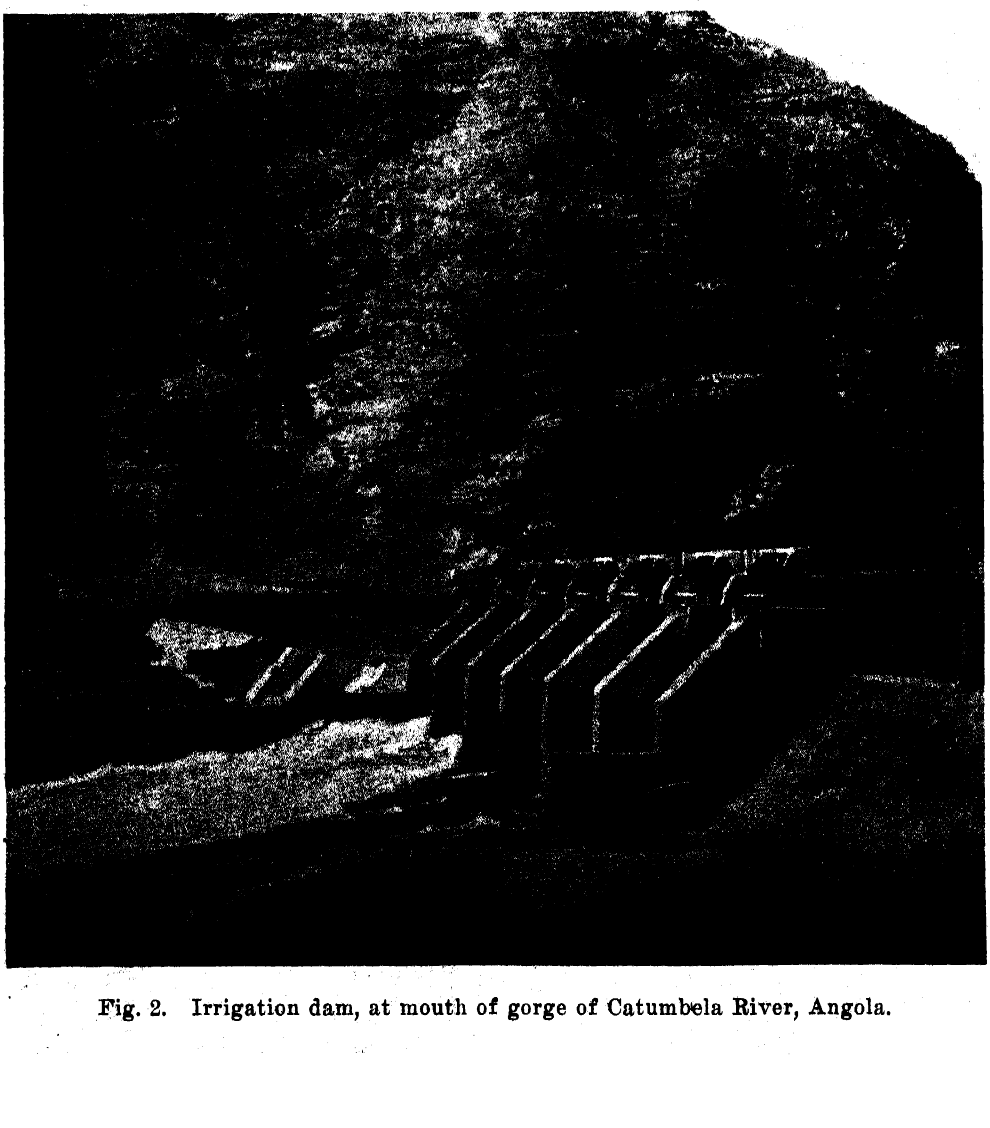


Fig. 2. Irrigation dam, at mouth of gorge of Catumbela River, Angola.

Fig. 3. Main irrigation ditch, sugar plantation, Angola.

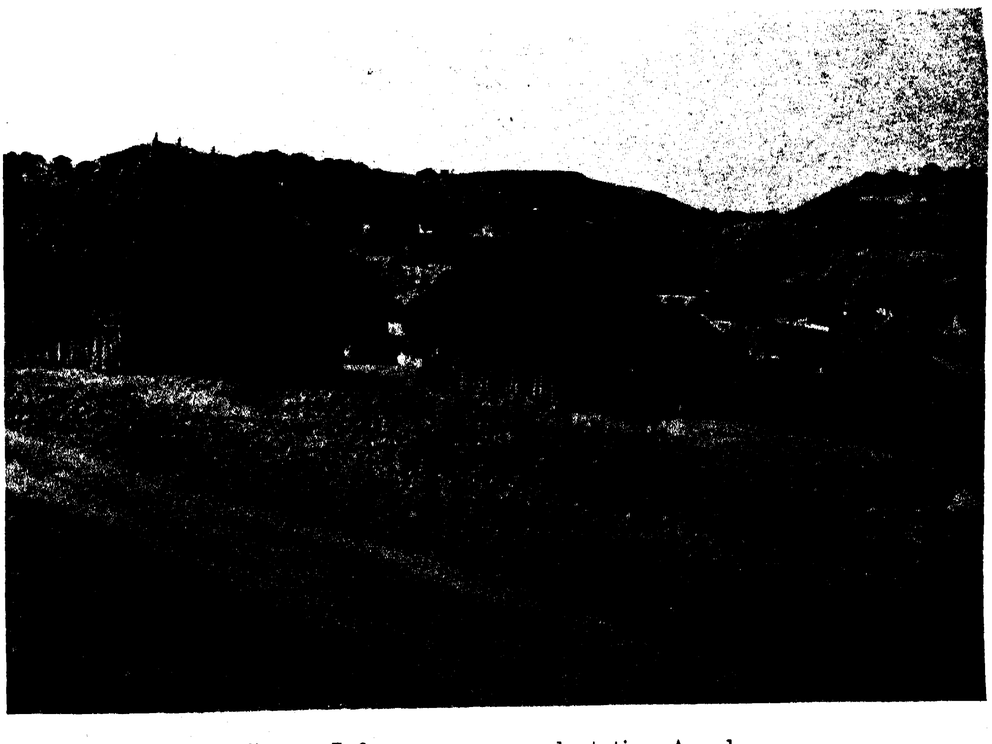


Fig. 4. Labor camp, sugar plantation, Angola.

Fig. 5. Nests of village weaver or palm bird on Raphia palm. Freetown, Sierra Leone, B. W. A.

Yams for Hawaiian Gardens—II

By E. L. Caum

Among the plants that might well be grown as accessory food crops in Hawaii, the yams take a prominent place. They are easy to propagate, yield heavily as a rule, are palatable and easy to prepare for the table.

The family of the yams, the *Dioscoreaceae,* is a large and complex group, widely distributed throughout the tropics and subtropics the world around. One species, which however is of very indifferent food value, is native to Hawaii. R. Knuth, who monographed the family in the monumental work "Das Pflanzenreich", recognized 655 species in the family, 614 of which belong to the genus Dioscorea, the true yams, the other 41 species being distributed among eight closely allied genera. If botanical and horticultural varieties are considered, the total number of kinds will in all probability exceed one thousand. Although many of these hundreds of species are of little or no economic significance, a number of them are food plants of importance in a greater or lesser degree. Several of them are sparingly grown in the Islands at the present time, and it seems as though more of them should be more widely planted.

In *The Hawaiian Planters' Record* for the second quarter of 1936 (pp. 171-182) was given a brief account of one of these species, the Spiny yam, *Dioscorea esculenta,* together with photographs of the tubers of other forms of Dioscorea. One form of *D. batatas,* the subject of the present sketch, is there illustrated (Fig. 13, p. 181). This plate is here reprinted as Fig. 1.

The Chinese yam or Chinese potato, *Dioscorea batatas,* is a native of China, Japan and Korea, and was described by Decaisne in the "Revue Horticole," Series IV, vol. 3 (1854), p. 243. It is a twining vine, 10 to 30 feet in length, with round or very slightly angular stems marked with purple, particularly on the exposed side. The leaves are opposite, obscurely three-lobed, the two lateral lobes rounded, the central one sharply pointed, 2½ to 4 inches long and somewhat less in width, 7 to 9 nerved, with a broad basal sinus (Fig. 2). There is a bright purple marking at the junction of the leaf blade and the short petiole. Usually, although not always, there is in each leaf axil a short recurved spine and very frequently one or two small potato-like aerial tubers (Fig. 3). The narrow spikes of white cinnamon-scented flowers arise singly or in clusters of two or three in the axils of the upper leaves. The odor of the flowers gives the plant the name "Cinnamon Vine" by which it is known on the mainland, where it is sometimes grown on arbors as an ornamental. The tubers are hardy and withstand the winters.

The tubers of the typical form of the Chinese yam are cylindrical, as much as four feet in length or even more, yellowish to gray-brown in color with white or yellowish inner skin and white flesh. They grow vertically, the upper end sometimes as much as three feet below the surface of the ground, and on that account difficult to dig. There are, however, a number of horticultural varieties. Makino, in "Nippon Shokubutsu Zukwan" (Illustrated Manual of Japanese Plants), states

that there are many named varieties of this yam grown in Japan, which differ from each other only in the size and shape of the tubers. One of these varieties, known to the Japanese as *tsukune*, bears tubers of two kinds. Some are flat and scalloped, while others are pestle- or flask-shaped, both forms being borne on the same vine. The upper left tuber in Fig. 4 is bifurcated, one half being flat, the other conic. Tubers of *tsukune* are occasionally imported from Japan, and small quantities of short tubers of the typical long cylindrical kind, called by the Japanese *nagaimo* (Fig. 1), are brought in from Japan and China. It is entirely probable that these yams are grown to some extent in Hawaii, although I have not found locally grown tubers in the markets. The species is listed in "Utilization and Composition of Oriental Vegetables in Hawaii" (Hawaii Agricultural Experiment Station Bulletin 60, December 1929, p. 55), but I believe the description and accompanying illustration are of another species of yam, probably a form of the widely distributed and extremely variable Winged yam, *Dioscorea alata.*

Of the various species and varieties of yams that are now growing in Hawaii or that may be grown as accessory food crops, the Chinese yam is probably the most difficult to harvest, due to the depth at which the tubers form. In making this statement I follow the literature. In the plants of *tsukune* grown in Manoa this past summer the tubers were just under the surface of the ground and were very easy to harvest, although the *nagaimo* tubers were much deeper. Opposed to the recorded difficulty in harvesting, however, are several advantages. The plant is easy to propagate: like all the yams, pieces of the tuber will grow. In the case of *tsukune* in particular, and this is probably the better variety of the two, the upper narrow neck may be used for planting material while the body of the tuber is used for food. As the latent buds at the upper end of the tuber germinate more rapidly than do those formed elsewhere, the amount of food material in the crop just harvested is reduced by the smallest possible amount in obtaining planting material for the next crop. Likewise the small aerial tubers may be planted, although they will not afford underground tubers of edible size in a single growing season. Fig. 5 shows the tiny pea-sized aerial "potatoes" and the subterranean tubers obtained in a single season from them. The second season will give tubers of usable size, probably about the size of those shown in Fig. 4, while after a third season they will be at their best. Although the plant has a short growing season—the Chinese yam will reach maturity and the vines die back in four to seven months as opposed to eight or nine months to a year for the Spiny and Winged yams—two or three of these growing periods are necessary to produce tubers of a size it is profitable to dig, depending on the size of the pieces planted. Tubers of *nagaimo*, cut up into pieces rather smaller than is best and planted in the Manoa Arboretum early in March, 1936, ripened off in seven months. The tubers were small, not more than half the size of those shown in Fig. 1. Tubers of *tsukune,* likewise cut too small, had grown their vines, flowered and died in less than four months. Some of this crop is shown in Fig. 4. In each case the crop was light and the tubers, although mostly of usable size, were small. Another growing season would put them at their best. These yams had been planted on a gentle slope in an abandoned cane field, and the soil was not prepared in any way. The cane and weeds were simply cut off and removed, and a shallow hole dug to receive the seed piece. Bamboo trellises were provided for

the vines. Had the land been plowed or even forked up sufficiently to remove the cane stubble, it is most probable that the crop would have been appreciably heavier. It would appear as though the best material for planting would be the smaller tubers, entire, rather than pieces of larger tubers, although this is pretty much a matter of choice.

The tubers are easy to prepare: I find in the literature nothing on the preparation of these vegetables other than a statement in the Hawaii Experiment Station bulletin previously mentioned, in which the instructions are: "Peel and wash. Slice in 2-inch squares one-fourth inch thick, and prepare as directed for arrowhead." The single recipe given for arrowhead is: "Wash and pare one-half pound arrowhead; . . . Slice one-half pound lean pork and mix with 1 teaspoon cornstarch, a little pepper, and one teaspoon soy sauce. Put in heated pot 1½ teaspoons peanut oil, one-half teaspoon salt, one slice ginger; add the pork and fry. Then add the arrowhead and stir vigorously for one minute. Add just enough water for gravy and cook over a slow fire until the vegetable is tender. Season and serve." These yams are used in other ways also. One method is to peel the tuber and grate it to a fine pulp which is eaten raw, seasoned with salt or soya and mixed with hot rice. Often the tubers are peeled and diced or cut into half-inch cubes and either steamed or cooked with soya and eaten as a side dish with meat or fish.

The Chinese yams, either the long cylindrical *nagaimo* or the smaller flat *tsukune*, are to the Chinese and Japanese what the Spiny yams are to the Filipinos.

Fig. 1. Tubers of *Dioscorea batatas,* variety *nagaimo.* These tubers, which were imported, are the most economical size.

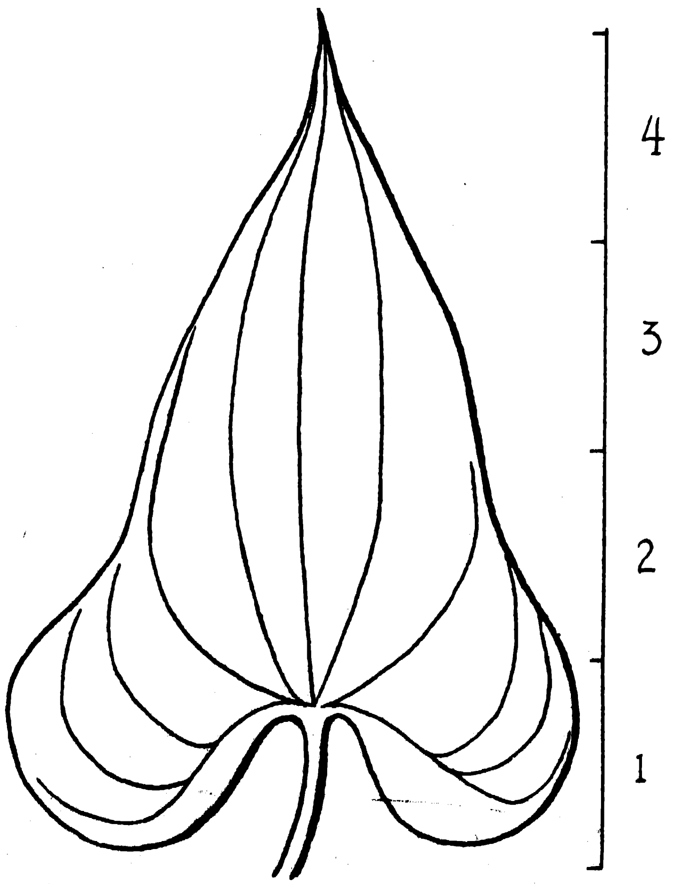


Fig. 2. A leaf of *Dioscorea batatas,* natural size.

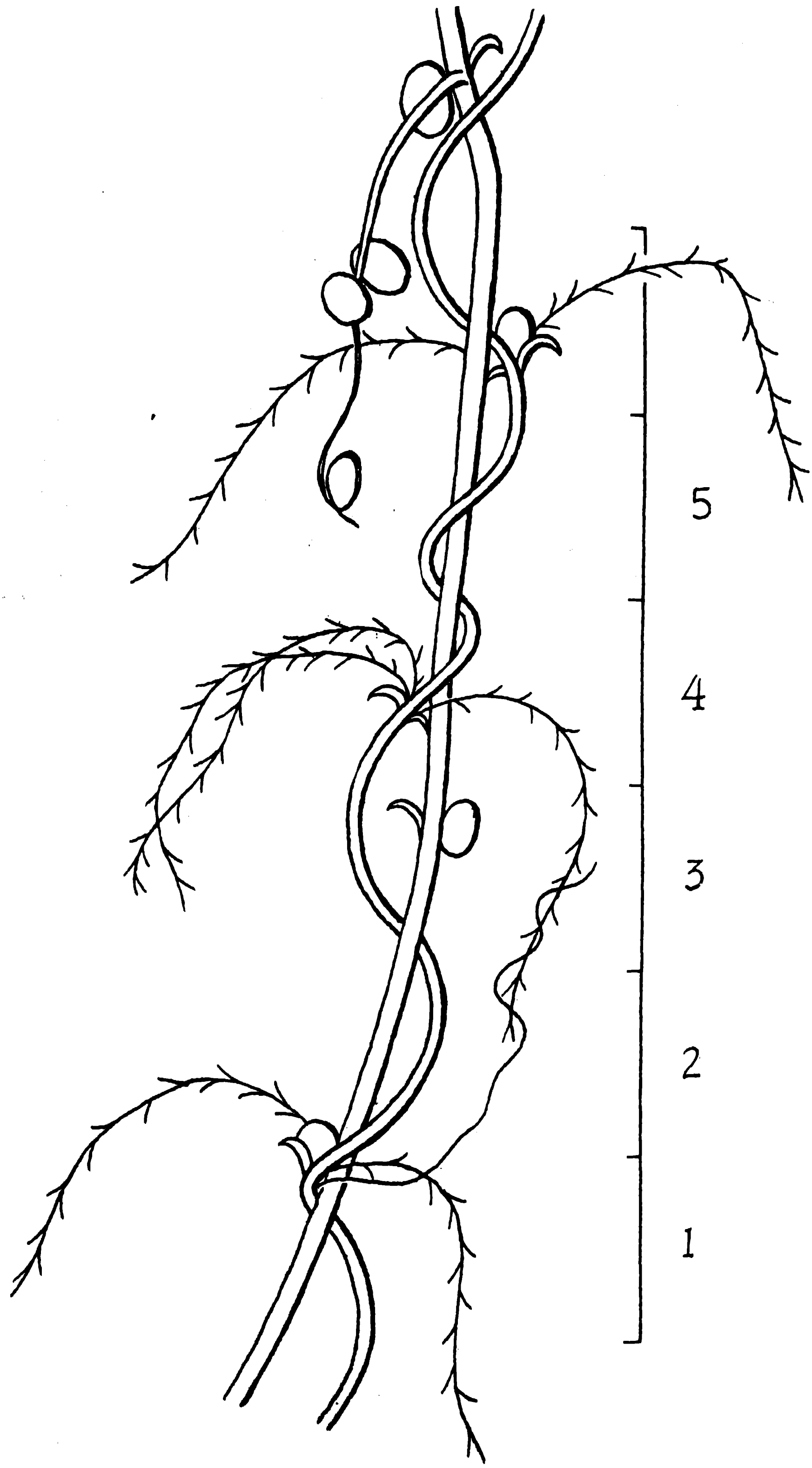


Fig. 3. A portion of the stem of *D. batatas,* (practically natural size), showing the axillary spines, the aerial tubers and the flower spikes.

Fig. 4. Small tubers of *D. batatas*, variety *tsukune*.

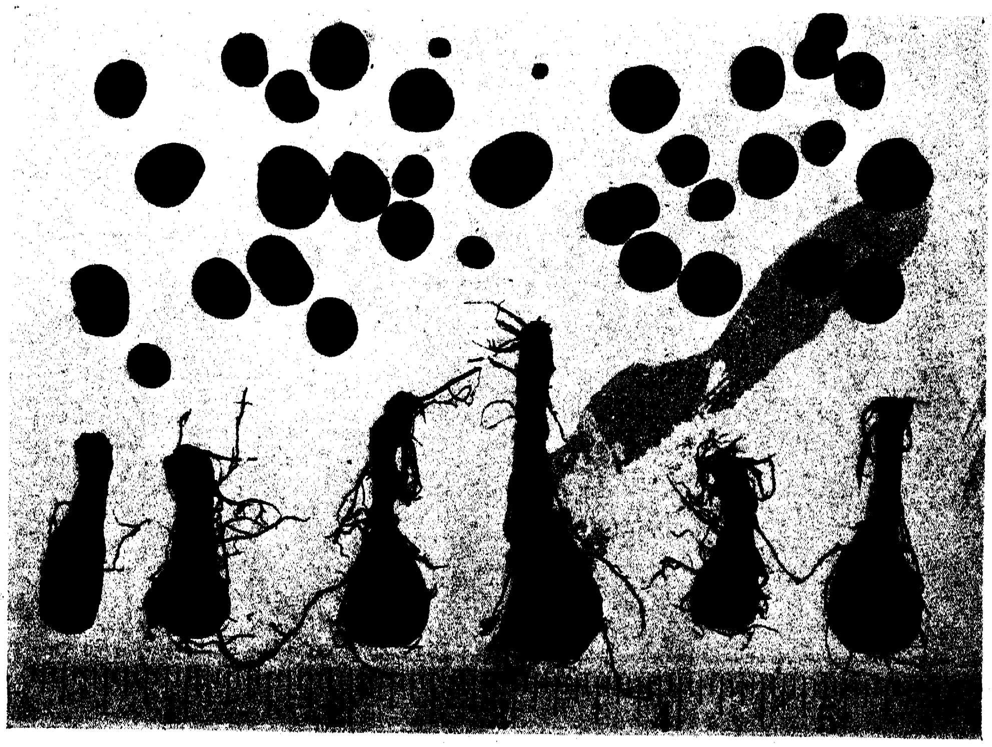


Fig. 5. Aerial tubers and first-season subterranean tubers of *D. batatas*.

Evaluation of Nitrogen in Molasses

By R. J. Borden

It is quite possible that the differences of opinion, which are found among plantation men regarding the value of molasses as a fertilizer for sugar cane, are the result of the differences in the conditions under which the effects of molasses on cane growth have been noted. And of such differences in conditions, we have special reference to differences in the available nitrogen supply of the soil, and to differences in the amounts of nitrogen fertilizer that were used along with the molasses applications that were made.

It is a well established fact that when a highly carbonaceous, quickly decomposable material like molasses, which has a wide carbon nitrogen ratio (estimated at about 50: 1), is added to a fertile soil, the resulting soil microbial growth is so greatly stimulated that there is immediate competition between the soil organisms and the crop plants for the soluble nitrogen that is there. During this period of increased microbial activity which probably continues as long as the ratio of carbon to nitrogen in the soil remains somewhat greater than 10 to 1, the crop plant is apt to suffer from nitrogen deficiency, and a low-nitrogen soil will show this effect more rapidly and for a more extended period than a nitrogen-rich soil.

The results of another investigation that we planned in order to determine the crop-producing value of the nitrogen contained in molasses that had been incorporated with the soil, have substantiated our earlier study* of this issue, for again we find no increases in harvested dry weights which can be credited to the nitrogen in the molasses.

The soil used was an acid (pH 5.8), porous, sandy loam from our Manoa substation, which when tested by our standard Mitscherlich procedure, showed only 53 pounds of available nitrogen per acre-foot. Chemical analyses revealed the total nitrogen at .212 per cent, which indicates somewhat over 5,000 pounds per acre-foot. Available potash was definitely low, as also was the availability of phosphate to the crop grown. After a thorough mixing, the soil was divided into four portions for four series of treatments with respective checks:

A—Nitrogen and molasses added together and soil thereafter fallowed in pots for 6 weeks before being planted.

B—Same as A but fallowed for 4 months before planting.

C—Molasses added alone and soil fallowed for 6 weeks before adding nitrogen and planting.

D—Same as C but fallowed for 4 months.

During the so-called fallow period, these soils were kept moist and aerated in a warm greenhouse, and covered to prevent contamination; hence conditions for a satisfactory microbial activity were provided after the molasses had been added.

*Borden, R. J., 1935. Some Plant Food Values in Molasses and Filter Cake. *The Hawaiian Planters' Record*, 39:180-190.

Sufficient phosphate and potash to produce a maximum growth of the indicator crop (Sudan grass) were supplied when the soils were potted, and the following 12 differentials were provided for in each series:

Group	Treatment Nos.	Pounds per Acre of Nitrogen From Molasses	Pounds per Acre of Nitrogen From Fertilizer	Total N
Low nitrogen	1	0	57	57
	2	32	57	89
	3	65	57	122
	4	0	122	122
Medium nitrogen	5	0	142	142
	6	32	142	174
	7	65	142	207
	8	0	207	207
High nitrogen	9	0	227	227
	10	32	227	259
	11	65	227	292
	12	0	292	292

Thus in Series A and B we have what amounts to applications of molasses at the rate of 3 and 6 tons per acre to soils which had varying amounts of available nitrogen at the time this molasses was incorporated, while in Series C and D the available nitrogen content of the soil was low at the time the molasses was added and continued low during the entire fallow period following its application. There is thereby afforded a comparison of the effect of a difference in the length of the period allowed between the time of applying the molasses and of planting the crop, when both nitrogen-rich (Series A and B) and nitrogen-poor (Series C and D) soils are concerned.

Each series, potted in Mitscherlich pots, was planted with Sudan grass seed at the end of its respective period of fallow. This makes it a little difficult to make direct comparisons of the actual dry weights of individual treatments in Series A and C, with those in Series B and D, for since they were grown at slightly different times of the season, such weights perhaps reflect some differences in sunlight conditions which may have existed during the respective growth periods. Other than this, however, the data offer some interesting comparisons.

The first crops from each series were harvested at the age of 86 days. The plants were cut off at the surface of the soil, dried, and weighed. The stubble left in the pots was then "knifed" to a depth of several inches as the surface soil was being loosened for replanting; no stubble or root material was removed from any pot, and no drainage was lost. All pots were then refertilized with phosphate and potash only, and two weeks later they were replanted for a second crop. A month after the harvest of this second crop, a similar procedure of preparation, fertilizing and planting was followed for a third consecutive crop for Series A and C only.

These second and third croppings, without the further addition of nitrogen fertilizer, were for the purpose of determining whether that nitrogen which had been withdrawn and become tied up by the soil organisms would ultimately be released for the use of the crop being grown. It was apparent very soon after each successive crop was started that there was no available nitrogen present, and at the end of

the successive 90- and 60-day growth period, the dry matter secured clearly substantiated this fact. Hence, we were unable to recover for the use of our crop that nitrogen which had been taken up or dissipated by the soil organisms, even though a period of more than 9 months had elapsed since the microbial activity had been stimulated by the application of the molasses.

Since the dry weights secured from the second and third croppings are so small, and the differences between treatments in these crops are such as might easily be due to chance alone, a discussion of the results may well be confined to the data from the original or first crop harvested. The complete harvest data are offered in Tables I and II, and to facilitate study the more pertinent parts are also offered in graphic form in Fig. 1.

Reference to Fig. 1 quite clearly brings out the significant features of the results that were secured. These may be briefly enumerated and discussed, as follows:

1. The application of molasses to this soil was responsible for a definite loss in the weight of the crop harvested therefrom. In general this loss was greater when the molasses application had been at 6 tons per acre than at 3 tons per acre.

2. This depressing effect of molasses on the amount of dry matter produced was most pronounced when the amount of available nitrogen was low; as more nitrogen was furnished, the detrimental effect of the molasses became less pronounced: this was true (a) regardless of whether the soil was fallowed for 6 weeks or for 4 months, and (b) whether the different nitrogen levels were established at the time the molasses was applied at the beginning of the fallow, or at the end of the respective periods of fallow when the crop was planted.

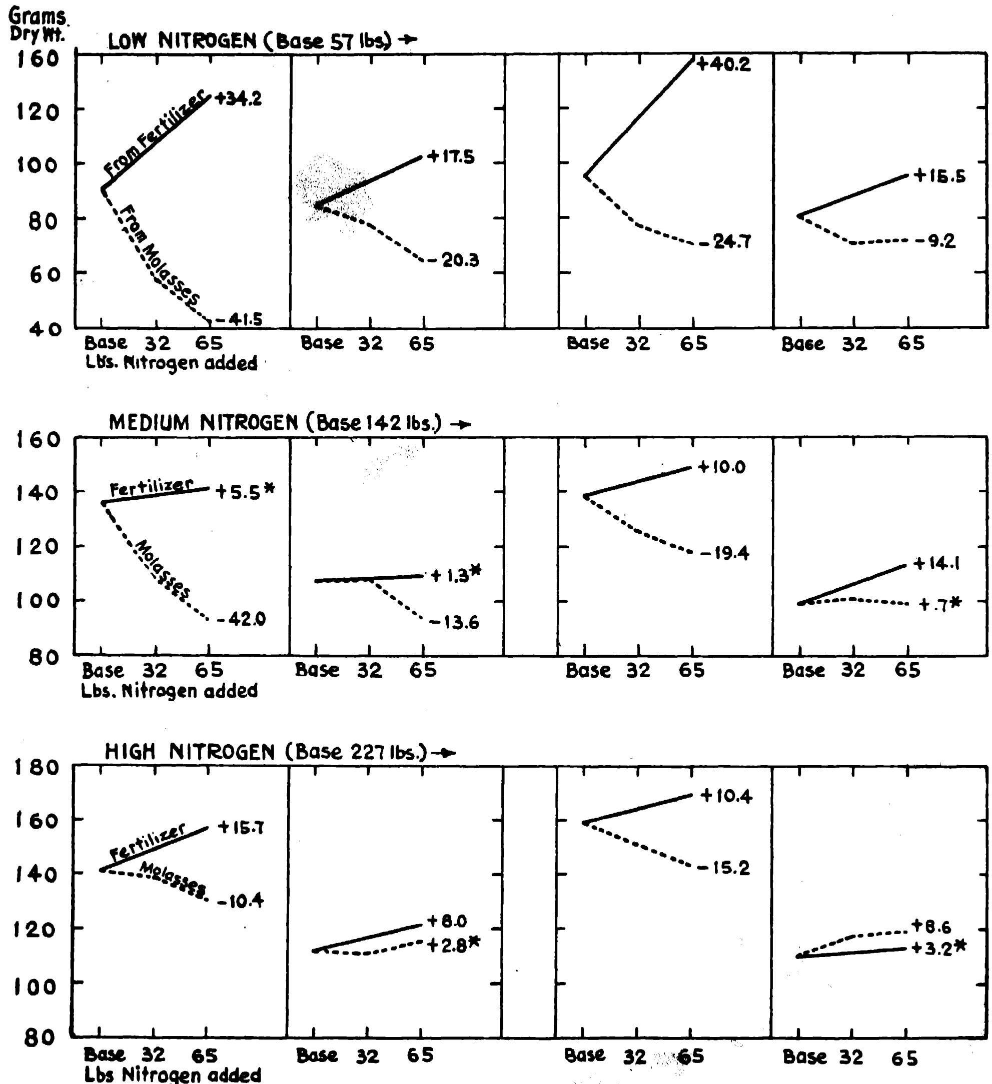
3. The losses in crop weights caused by the molasses applications were considerably greater when the crop was planted 6 weeks after molasses had been incorporated with the soil than when planting was delayed for 4 months. This was true, (a) regardless of whether the nitrogen was added at the same time as the molasses or 4 months later and, (b) with either low, medium, or high levels of available nitrogen.

4. Except in one case, we note that when a high nitrogen level was furnished the losses due to molasses were considerably reduced when the nitrogen was not applied with the molasses at the beginning, but was furnished at the end of the fallow period when the crop was planted.

5. Only in the case of a relatively high available nitrogen level, and when at least four months had elapsed between the application of molasses and the planting of the crop, did we find any indication at all that some of the nitrogen in the molasses may be released for the use of our crop, and this evidence is not entirely convincing. Thus we are led to the same conclusion that has been reached by many other research workers, i. e., that when the soil micro-organisms have been stimulated by supplying them with an easily decomposable carbonaceous material, there will most likely result an available nitrogen shortage for any crop plants growing on such soil. In addition, as yet, we have been unable to demonstrate that this nitrogen, which has been withdrawn by these micro-organisms during their greatly stimulated activity period, will be returned for use by the crops which follow when normal microbial conditions again prevail. Thus the initial nitrogen loss, which is clearly demonstrated, would appear to be a more or less permanent one, and we are therefore forced to admit doubt that the nitrogen content of molasses has any real value as a plant food which can be economically substituted, even in part, for a commercial nitrogen fertilizer.

Nitrogen and Molasses during Fallow — Series A (6 weeks fallow), Series B (4 months fallow)

Molasses only during Fallow — Series C (6 weeks fallow), Series D (4 months fallow)



* Amount of difference may likely be due to chance (less than 2 x SEd).

Fig. 1. Showing the total dry weights; also the amounts of gains and losses (as grams dry matter) for the addition to the base amounts indicated, of 65 pounds of nitrogen from fertilizer (solid line) and from molasses (broken line).

TABLE I

Nitrogen Status		Treatments: Amt. Molasses applied (tons per acre)	Pounds Nitrogen per acre: From Molasses	From Fertilizer	Total	Series A (fallowed 6 weeks) Avg. Dry Weight (grams ± SEd): First Crop	Second Crop	Third Crop	Total Three Crops	Series B (fallowed 4 months) Avg. Dry Weight (grams ± SEd): First Crop	Second Crop	Total Two Crops
Low	1	None	0	57	57	84.8±2.6	7.7±.1	4.2±.3	96.7	84.2±3.3	2.4±.2	86.6
	2	3 tons	32	57	89	57.7±1.6	8.5±.4	2.8±.2	69.0	78.3±2.5	2.9±.2	81.2
	3	6 tons	65	57	122	43.3±1.2	9.2±.2	3.5±.2	56.0	63.9±4.2	3.6±.3	67.5
	4	None	0	122	122	122.0±1.4	5.8±.3	4.1±.2	131.9	101.7±1.5	2.9±.0	104.6
Medium	1	None	0	142	142	135.7±2.0	6.2±.5	3.9±.3	145.8	107.1± .1	2.9±.1	110.0
	2	3 tons	32	142	174	108.5±1.0	8.7±.4	3.2±.2	120.4	107.9± .2	3.1±.1	111.0
	3	6 tons	65	142	207	93.7± .2	10.4±.2	2.9±.2	107.0	93.5±1.6	2.6±.0	97.1
	4	None	0	207	207	141.2±1.7	6.3±.0	3.5±.5	151.0	108.4±1.2	3.2±.1	111.6
High	1	None	0	227	227	141.1±1.7	6.0±.8	3.4±.1	150.5	112.5±1.4	3.3±.2	115.8
	2	3 tons	32	227	259	139.3±2.0	7.1±.1	3.3±.0	149.7	111.4± .0	2.8±.2	114.2
	3	6 tons	65	227	292	130.7± .8	9.0±.8	4.1±.1	143.8	115.3±2.9	3.3±.3	118.6
	4	None	0	292	292	156.8± .5	7.1±.2	3.0±.5	166.9	120.5±1.9	3.1±.1	123.6

In both Series A and B, the nitrogen variables were present throughout their respective fallow periods.

TABLE II

Nitrogen Status		Treatments: Amt. Molasses applied (tons per acre)	Treatments: Pounds Nitrogen per acre From Molasses	From Fertilizer	Total	Series C (fallowed 6 weeks) Avg. Dry Weight (grams ± SEd) First Crop	Second Crop	Third Crop	Total Three Crops	Series D (fallowed 4 months) Avg. Dry Weight (grams ± SEd) First Crop	Second Crop	Total Two Crops
Low	1	None	0	57	57	95.6± .6	6.9±2.3	3.2±.0	105.7	80.7±2.5	2.9±.2	83.6
	2	3 tons	32	57	89	77.4±3.7	8.5±1.9	4.6±.6	90.5	70.8±3.9	2.9±.0	72.7
	3	6 tons	65	57	122	70.9±1.5	10.8± .4	3.8±.1	85.5	71.5±2.8	2.9±.1	74.4
	4	None	0	122	122	135.8± .3	7.5± .2	3.6±.1	146.9	96.2±5.4	2.6±.1	98.8
Medium	1	None	0	142	142	137.7± .9	7.8± .8	3.3±.2	148.8	98.6±5.7	3.2±.6	101.8
	2	3 tons	32	142	174	126.1±1.3	9.8± .8	3.4±.6	139.3	101.1±2.2	3.0±.3	104.1
	3	6 tons	65	142	207	118.3± .4	10.1± .4	3.8±.2	132.2	99.3±1.3	3.2±.4	102.5
	4	None	0	207	207	147.7±1.4	6.8± .2	3.3±.4	157.8	112.7±2.1	3.3±.4	116.0
High	1	None	0	227	227	159.0± .4	7.3± .4	2.9±.3	169.2	110.6±1.6	3.0±.2	113.6
	2	3 tons	32	227	259	150.8±1.4	8.5± .4	3.3±.2	162.6	117.5±5.3	2.9±.1	120.4
	3	6 tons	65	227	292	143.8±4.9	8.1± .4	3.0±.1	154.9	119.2±2.1	3.6±.1	122.8
	4	None	0	292	292	169.4±1.4	6.6± .6	3.5±.4	179.5	113.8±3.9	3.3±.1	117.1

In both Series C and D, the nitrogen variables were not added until the end of the respective fallow periods.

Summary of Laboratory Studies of Anomala, 1933-1935

By R. H. Van Zwaluwenburg

Anomala Coefficient

Almost ever since the recognition of *Anomala orientalis* as a cane pest on certain areas in the Pearl Harbor district of Oahu, it has been obvious that economic loss is heaviest in the light, residual, red soils of the upland fields, and that box canyon fields of alluvial soil, even when surrounded by heavily infested fields, never suffer noticeably from the grubs. Serious outbreaks of Anomala, renewed in 1930, after several years of apparent control by natural agencies, made it important to learn what essential differences exist between soils heavily infested and those apparently immune. The answer was believed to lie in some physical difference between the soils themselves, and, as this was a problem beyond the scope of unaided entomological investigation, the assistance of H. A. Wadsworth, professor of soil physics at the University of Hawaii, was enlisted early in 1933.

After a scrutiny of results secured from a measurement of the physical properties of soils coming from areas of known Anomala history, a relationship was proposed which, although crude, proved to be a valuable index of a soil's susceptibility to Anomala infestation:

$$\frac{\textit{Ignition loss}}{\textit{Moisture equivalent}}$$

The resulting quotient is termed the "Anomala coefficient". It is *of value only in soils having a negligible organic content,* as is the case with all the lateritic and alluvial soils throughout the area involved.

Previous soil investigation in Hawaii indicates that upland soils (among which are the Anomala areas) are relatively rich in colloidal iron and aluminum, and poor in colloidal silica and alumino-silicates. A characteristic of soils high in iron and aluminum colloids is a high ignition loss.* With only a low moisture equivalent reading, and no other data, it is impossible to know whether a soil is low in colloidal material or whether there is present a larger percentage of colloids of low water-holding capacity. But if there is the added information that the ignition loss is high, it is safe to assume that the soil contains a large amount of colloidal material, and a relatively large amount of some intensively weathered form of iron or aluminum. Such weathering adds water in such a form that it remains in the soil when dried at 105° C. but is completely given off at the higher temperature (900° C.) to which ignition-loss samples are subjected. Hence the Anomala coefficient is a

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* *Ignition loss* is determined as follows: The soil sample is oven-dried at 105 degrees Centigrade to get the constant weight; it is then ignited for 30 minutes at 900 degrees Centigrade. The resulting loss in weight is then divided by the original oven-dried weight to obtain the ignition loss.

Moisture equivalent is determined by the following method: The sample is placed in a small brass box provided with screen and filter paper bottom. The soil is saturated and subjected to a centrifugal force equivalent to 1000 times the force of gravity. The percentage of moisture remaining in the soil after 30 minutes in the centrifuge is the moisture equivalent.

measure of colloidal iron and aluminum content; a high content of these materials is a striking characteristic of soils susceptible to severe Anomala damage in Hawaii.

The application of this work to field observations results in the following soil classification:

Class 1. Soils not susceptible of commercial damage from Anomala. Anomala coefficients less than 0.45.

Class 2. Soils susceptible of moderate commercial damage. Anomala coefficients from 0.45 to 0.65.

Class 3. Soils susceptible of great commercial damage. Anomala coefficients more than 0.65.

Low Anomala coefficients are associated with soils that rapidly dry into hard clods or lumps to an appreciable depth. High Anomala coefficients are associated with soils that dry into light, fluffy masses, free from clods and cracks; the subsoil protected from drying acts as a suitable medium for Anomala development for long periods, even in the absence of rainfall or irrigation.

The value of the Anomala coefficient lies principally in the assurance which it gives most of the cane plantations in the Territory that Anomala will probably never assume first-rate proportions as a pest in their areas, even should it pass the boundaries of its present range. On Oahu it is fairly certain that Anomala already occupies all of the area favorable to its existence in destructive numbers. On Maui and on Kauai there are limited cane areas in which, if the concept is sound, the beetle could increase to destructive numbers; this information prompts us to watch these areas with especial care. The extreme dependence of Anomala upon favorable moisture conditions makes it easy to understand why it has never been found in unirrigated land devoted to pineapples.

Soil Moisture

Study of contrasting soil types reveals that the crux of the difference between them is the effect upon Anomala eggs of the rapidity with which the unfavorable soil loses free moisture, as contrasted with its retention by the favorable soil. The two types may even show identical percentages of moisture content, but the unfavorable soil holds more of this water so tightly that it is unavailable to the eggs. Absorption of moisture from the surrounding medium is essential to the development and hatching of the egg. Unfavorable soil loses its available moisture remarkably rapidly, and Anomala eggs placed in mudballs of such soil collapsed within 24 hours and died, presumably due to the withdrawal of water from the egg by the soil. In mudballs of favorable soil the originally added moisture was sufficient for normal development and hatching. So long as moisture is maintained at the point necessary for incubation, it makes no difference if the soil is of the favorable or unfavorable type; the same percentage of hatching results in approximately the same time.

It was originally thought that the tendency of unfavorable soil to harden and lump was the essential deterrent to Anomala development, due to the difficulty which grubs must meet in working through such soil to find food. This may be

partially true, especially with newly hatched grubs, but mature grubs can make their way through even dry, lumpy soil, with remarkable ease. In unfavorable soil, kept adequately moist at all times, newly hatched grubs travel through the sticky mass with little difficulty.

Effect of Humidity Differences Upon Incubation of Eggs

Apparently Anomala eggs gain moisture for their development from the air in the soil. If the relative humidity of the soil air is high, such supplies of moisture are easily available. If the humidity is relatively low, egg development is hindered and under extreme conditions a marked collapse of the eggs occurs. Of striking significance is the narrow range of relative humidities which can be tolerated by eggs of this species.

The degree of moisture depletion of the soil air necessary to kill Anomala eggs was found to be extremely slight. Having determined that eggs hatch normally under favorable moisture conditions, even in the absence of soil, Prof. Wadsworth and the writer set up series of sealed chambers having various ranges of relative humidity controlled by different solutions of sulphuric acid. Reductions in relative humidity were found to affect not only the percentage of eggs hatching, but to influence also the length of incubation period. The following figures (at an average mean room temperature of about 78° F.) are characteristic of the results obtained:

Per cent Relative Humidity	Incubation Period	Percentage of Hatch
100	14.8 days	100
99.5	16.0	95.0
98.7	17.4	95.0
97.9	17.8	30.0
97.1	18.0	5.0
96.3	....	0

The critical point for the eggs in the above experiment lay between 98.7 and 97.9 per cent relative humidity. The soil atmosphere in soil moistened to the maximum field capacity, is 100 per cent; at the wilting point it is about 99 per cent.* In another experiment in which the soil was moistened somewhat above the maximum field capacity (but not flooded) hatching was delayed; the percentage of hatch was nearly that of the check (100 per cent relative humidity).

Life-History Studies

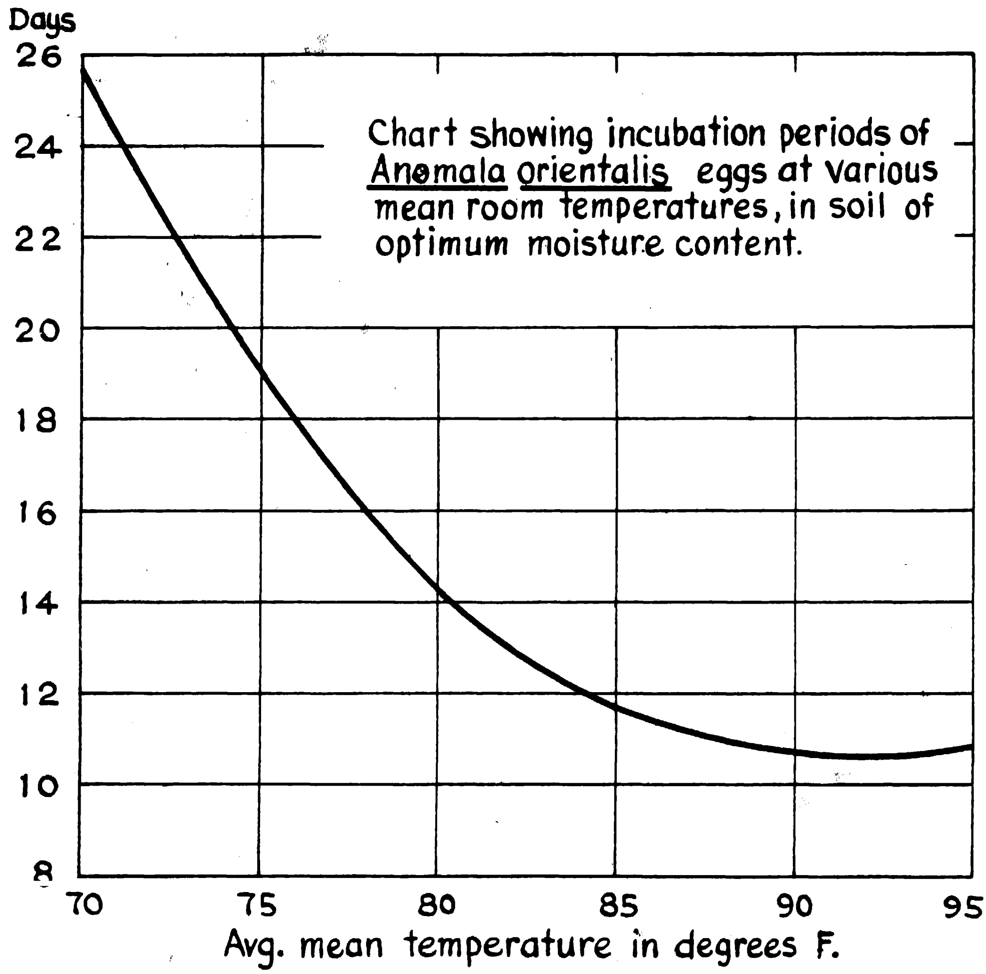
Egg stage:

As is to be expected, there is a definite inverse correlation between temperature and length of incubation. The accompanying illustration shows the average incubation period of Anomala eggs in soil of approximately the optimum moisture content, for various average mean temperature (Fahrenheit).†

* Recent work by Schofield (International Congress of Soil Science, 1935, Vol. 2, pp. 37-48) suggests that the permanent wilting per cent for some soils is associated with a relative humidity of 98.9 per cent. (H. A. Wadsworth.)

† We are indebted to the local laboratory of the U. S. Bureau of Entomology and Plant Quarantine for the use of constant-temperature cabinets in these and other experiments.

In the field Anomala eggs are normally laid within the first foot of soil, and it is not probable that they ever meet the upper extremes of average temperature shown on the chart. Average soil temperatures at a depth of 12 inches, in fields in the upper and middle Anomala belts, may be expected to show ranges, depending upon the season, comparable to the following, calculated on the basis of work by Das (*The Hawaiian Planters' Record,* 38; p. 79, 1934) and Weather Bureau figures (Upper Hoaeae, elevation 705 ft., 1925-1934):



Soil covered by cane crop..................	61.5 to 69.0 degrees F.
Bare soil..............................	69.5 to 76.9 degrees F.

In dry soils the figures would be somewhat higher, and there would be a greater daily fluctuation than in soils kept moist by irrigation.

Repeated unsuccessful attempts to hatch Anomala eggs in a constant temperature of 100° F., prompted the following experiment to determine how long an exposure to this temperature is necessary to kill all eggs. Ten vials of 14 newly laid eggs each were put in a constant temperature cabinet, and at 24-hour intervals one

vial was withdrawn and placed at room temperature (which averaged about 78° F.). Hatching was as follows:

Hours exposure to 100° F. before removal to room temperature	Average incubation period	Percentage hatching
24	14.6 days	50.0
48	17.1	23.0
72	17.5	30.7
96	18.0	15.3
120	18.5	14.2
144	....	0
168	....	0
192	....	0
216	....	0
240	....	0

No eggs hatched after exposure to a constant 100 degree temperature for 144 hours or longer.

Hagan, working at Wahiawa, elevation 900 feet (*Soil Science,* 36, pp. 83-95, 1933), found that in uncovered soil at the ¼-inch depth, summer temperatures frequently rose to above 104 degrees for two hours or more, and that at 3 inches they occasionally rose to between 100.4 and 104 for two hours or longer. Accordingly, Anomala eggs in soil of optimum moisture content were exposed in a constant temperature cabinet for two hours daily to temperature of 104 degrees, followed by removal to room temperature. These eggs took slightly longer to hatch than did a check lot held at room temperature, but the percentage of hatching was about the same. This indicates that even if eggs are laid in bare soil within 3 inches of the surface they can survive the high diurnal temperatures encountered there, provided adequate moisture is present.

Pupal stage:

As with eggs, there is an inverse correlation between temperature and the duration of the pupal stage of Anomala. This is shown by the following figures, obtained in the quarantine laboratory from pupae kept on the surface of moist soil:

	Males		Females		Average mean
Pupating in	No.	Average	No.	Average	temperature
January	9	11.4 days	12	11.1 days	75.2 F.
February	56	11.2	50	10.8	75.7
March	75	10.5	112	10.1	76.1
April	14	10.6	14	10.2	76.0
May	35	9.3	64	9.1	79.6
June	3	9.1	16	8.7	80.6

Throughout the beetle order, so far as the writer knows, females take longer in the pupal stage than males; hence the reverse condition, demonstrated above and shown by critical examination to be statistically significant, is of interest. Possibly female adults remain for a time in the soil where they have pupated, before issuing above ground.

Miscellaneous:

The following miscellaneous data were obtained from 77 reared Anomala females kept in the laboratory with males always present, and fed on flower blossoms or apple:

	Average	Minimum	Maximum
Preoviposition period	7.1 days	4.5 days	18.5 days
Actual days of egg laying	8.3 days	2 days	14 days
Total egg laying period	11.4 days	2 days	23 days
Eggs laid per female	32.1 eggs	10 eggs	67 eggs

Females surviving from 1 to 10 days after last egg laying: 43.

Longevity of adult beetles:

The following data were obtained from mated, reared adults confined in jars of moist soil, and fed regularly; included are 77 laying females and 7 that died without laying any eggs:

	No. beetles	Average life	Minimum	Maximum
Females	84	17.3 days	1.5 days	30 days
Males	88	18.0 days	2 days	48 days

In addition, 3 unmated females lived 23.5, 25.5 and 29.5 days respectively, laying a total of 26 eggs, none of which hatched.

Summary of life history:

From the foregoing data the following approximate life cycle has been estimated for beetles hatching from eggs laid during the spring months:

Egg stage	14- 25 days
Grub stage	120-130 days
Pupal stage	9- 11 days
Preoviposition period	5- 18 days
Total	148-184 days

There is a wide individual variation in the length of the grub stage particularly; some grubs take over twice the indicated time to complete their development.

The above estimates agree fairly well with rearing experiments conducted in the open at Waipio with the assistance of J. S. Rosa. In an effort to get seasonal data on life history under simulated field conditions, 5 tubs of soil planted to cane were started monthly and seeded with 50 eggs each; these were kept under favorable moisture conditions by additions of water. From 35 tubs (5 per month from December to June) with 50 eggs each, only 9 Anomala were reared to the adult stage. While a low survival, the results are comparable to those obtained by other

workers (e.g., Bianchi, *The Hawaiian Planters' Record,* 39: 234-255, 1935). The 9 beetles required the following lengths of time to attain the adult stage:

From eggs laid in:	Days from egg to adult:
December	160 - 163
January	140 - 143
"	152 - 155
"	181 - 184
February	166 - 170
"	169 - 172
March	165 - 168
"	165 - 168
June	165 - 175

The average time from egg to adult stage was 164.5 days; individual variation ranged from 140 to 184 days. Incidentally this experiment proves that if the moisture factor is kept favorable, Anomala can develop successfully in even an unfavorable soil, for due to a misunderstanding the work was conducted with soil having an Anomala coefficient of 0.44.

Miscellaneous Observations

Ratio of sexes:

Of a total of 520 beetles reared in the laboratory from grubs collected in the field, 309 were females, and 211 males. This is roughly in the ratio of 3 females to 2 males.

Effect of submergence on egg-hatching:

Fifty newly laid eggs were placed in soil, and one inch of water allowed to stand on the surface for 10 days. At the end of that time the eggs were removed to favorably moist soil, and eventually 38 per cent hatched normally; a check lot showed 97 per cent hatch.

Fertility of eggs:

Seven hundred twelve eggs from field-collected female beetles, kept in jars of moist soil in close confinement with males, showed 98 per cent fertility. Under the circumstances females could hardly escape mating, but the experiment is perhaps comparable to conditions in heavily infested fields. Eggs from unmated females, as previously noted, do not hatch.

Occurrence of black-phase beetles:

Anomala adults which are blackish instead of the more usual strawcolor, are common in the field. Laboratory study indicates that there is no important differ-

ence between the black and the light phases with regard to fertility and longevity. The relative abundance of the two phases, compiled from local data is as follows:

		Black-phase beetles	
Field-collected	Total beetles	No.	Percentage of total
O. H. Swezey (1916-1925)	2253	593	26.3
F. A. Bianchi (1930-1932)	689	176	25.5
Total	2942	769	26.2
Laboratory-bred			
January-March	314	69	
April	28	5	
May	99	27	
June	19	3	
Total	460	114	24.7
Total of both field-collected and laboratory-bred beetles	3402	873	25.6

Arsenic concentrations lethal to newly hatched grubs:

Laboratory experiments with extremely thorough mixtures of white arsenic and soil, prepared by the Chemistry department, placing Anomala eggs in the soil and leaving the hatching grubs exposed to the poison for 14 days after hatching, show that concentrations of 250 parts or more per million (by weight) of white arsenic, causes a very high mortality of young grubs. Assuming a weight of from 2.5 to 3 million pounds per acre-foot for typical Anomala soils, a reasonably effective control of newly hatched grubs is to be expected from applications of from 625 to 750 pounds of white arsenic, mixed in the top foot of soil.

The Synthesis of Sucrose by Excised Blades of Sugar Cane

By Constance E. Hartt

In a study of the fluctuations of sugars in the leaf blades of the sugar cane plant during the day and the night (3), the author stated that it is impossible in the present state of our knowledge to give a decisive answer to the question whether cane sugar or the simple sugars arise first in the process of photosynthesis. If the simple sugars arise first, then there must be present in the leaf of the sugar cane plant a mechanism for the conversion of simple sugars to cane sugar. The purpose of this paper is to present evidence indicating that the leaf blade of the sugar cane plant can manufacture cane sugar when supplied with the simple sugars—glucose and fructose.

Methods

The plants used in this investigation were of the variety H 109, planted in pots of good soil and kept in a sunny part of the grounds of the Experiment Station. The plants, which had been ratooned on November 30, 1935, were given uniform fertilization and irrigation under the direction of Dr. A. J. Mangelsdorf. The same plants were used in a study of water and cane ripening. For the investigation reported herein, the leaves only were taken. Counting the leaf with the highest visible dewlap as leaf number one, leaves number two and three were used in each test. The leaves were cut between eight and nine o'clock in the morning and were placed immediately in the required solutions. The studies now reported deal with samples of leaves taken between July 20 and September 17, 1936.

All of the tests were conducted in the constant-temperature room, at room temperature, in absolute darkness.

Analyses were made of moisture and sugars using the methods cited in a former paper (2). Cane sugar was determined by inversion by a solution of Wallerstein invertase scales according to the method of Hassid (4).

Results

Experiment 1. Feeding with glucose and/or fructose results in an increase in sucrose:

The blades were cut at 8:20 a. m., July 20, 1936, and were placed in flasks of distilled water in the constant-temperature room at 8:35. After 24 hours, the blades were removed from the water, their ends wiped dry, and they were then placed in the sugar solutions for 24 hours in the dark, each blade in 300 cc. solu-

tion. The ends of the blades were rinsed with distilled water, wiped, and the leaves were then sampled. The following series were taken:

1: Untreated
2: Water 24 hours
3: Water 24 hours, and then 10 per cent glucose 24 hours
4: Water 24 hours, then 5 per cent glucose plus 5 per cent fructose 24 hours
5: Water 24 hours, then 10 per cent fructose 24 hours

The results of the determinations of moisture and sugars are presented in Table I, which shows that keeping excised blades in darkness in water for 24 hours resulted in an increase in percentage of moisture. The changes in percentages of the sugars were within the limits of experimental error.

The percentage of simple sugars in the blades was more than doubled by supplying them with glucose or fructose or both. The differences in sugar content between Series 3, 4, and 5, are probably explained by the fact that in this first test the sugar solutions were not prepared quantitatively.

TABLE I

Moisture and Sugar Percentages in Blades in Experiment 1; Moisture Percentages Expressed Upon the Wet-Weight Basis; Sugar Percentages Upon the Dry-Weight Basis

Series	Moisture	Simple Sugars	Cane Sugar	Total Sugars
1: Untreated	65.94±0.067	0.996±0.040	2.376±0.115	3.497±0.161
2: Water	69.84±0.205	1.083±0.019	2.399±0.003	3.609±0.016
3: Water, glucose	65.24±0.105	2.631±0.014	7.892±0.173	10.939±0.196
4: Water, fructose + glucose	65.95±0.100	3.061±0.005	9.272±0.005	12.822±0.004
5: Water, fructose	65.87	3.351±0.008	9.018±0.057	12.844±0.069

The percentage of cane sugar in the blades was nearly trebled by supplying them with glucose or fructose or both.

Before concluding from this experiment that the blades absorbed glucose and fructose and synthesized cane sugar therefrom, it is necessary to consider other possible explanations of these results. Fortunately we are dealing with cut blades and know that no changes can be due to translocation from other organs. The changes must be due either to absorption from the solution supplied, or to rearrangements within the leaf, the study of which was the object of the second experiment.

Experiment 2. A complete nutrient solution did not increase the percentages of sugars:

The suggestion may be made that during the second 24-hour period in Experiment 1 there may have been a breakdown of starch or other polysaccharides resulting in higher percentages of sugars, due to a higher osmotic concentration or withdrawal of water. To determine this point, an experiment was conducted in which a balanced nutrient solution of osmotic concentration approximately equal to that of the sugar solutions used in Experiment 1 was employed.

The solution was prepared as follows. Since a 10 per cent solution of glucose equals 100 grams per liter, and a gram molecular solution of glucose equals 180.15 grams per liter, the solution used in Experiment 1 was approximately ½ gram molecular, and had an osmotic pressure of about 11.2 atmospheres, not being ionized. A balanced nutrient solution of approximately 11.2 atmospheres pressure was therefore prepared using potassium phosphate, calcium nitrate, and magnesium sulphate.

The blades were cut on August 12 and placed in the dark for 24 hours. Seven blades were used in each series for the determination of sugars, and each blade received 100 cc. of water or solution.

The following series were distinguished:

1: Untreated
2: In water 24 hours
3: In solution 24 hours

After 24 hours in the dark, the blades of Series 2 were normal in appearance, while those of Series 3 were somewhat dried, rolled, a little stiff in texture, were less green, and had developed reddish streaks throughout almost their entire length.

The percentages of moisture and sugars are presented in Table II, which

TABLE II

Moisture and Sugar Percentages in Blades in Experiment 2; Moisture Percentages Expressed Upon the Wet-Weight Basis; Sugar Percentages Upon the Dry-Weight Basis

Series	Moisture	Simple Sugars	Cane Sugar	Total Sugars
1: Untreated	69.09±0.114	1.074±0.008	2.214±0.004	3.404±0.012
2: Water	67.72±0.229	0.734±0.019	1.607±0.017	2.426±0.002
3: Solution	64.53±0.119	1.032±0.028	1.625±0.020	2.743±0.007

shows that the blades kept for 24 hours in the concentrated solution lost water. Their content of simple sugars remained the same as that of the untreated blades, which was a little larger than that of Series 2 (in water). The cane sugar content decreased in the dark, being the same as that of the series in water. Thus although the concentration of the external solution was sufficient to cause a decrease in water content in the blades, there is no evidence of an increase in cane sugar resulting therefrom.

Therefore, unless the changes in the blades obtained in Experiment 1 were due to some internal factor other than loss of water or change in osmotic concentration, the evidence indicates that excised blades of the sugar cane plant can manufacture cane sugar in the dark, when supplied with glucose or fructose or both.

Experiment 3. Effect of concentration of glucose:

The blades were cut on August 19 and were immediately placed in the requisite solution, 100 cc. of water or solution for each blade. Fourteen blades were used

in each series, half of which were kept for the determination of invertase, to be reported later. The series were as follows:

1: Untreated
2: 24 hours in water
3: 24 hours in 1 per cent glucose
4: 24 hours in 2 per cent glucose
5: 24 hours in 5 per cent glucose
6: 24 hours in 10 per cent glucose
7: 24 hours in 25 per cent glucose

With the exception of Series 1, the blades remained in their respective solutions for 24 hours, after which time the blades of Series 2-6 were in uniformly good condition, while the blades of Series 7 were rolled.

The results of the determinations of moisture and sugars are recorded in Tables III and IV and Fig. 1, which show that the greater the percentage of glucose supplied, the greater the percentage of sugars within the leaf.

TABLE III

Moisture and Sugar Percentages in Blades in Experiment 3; Moisture Percentages Expressed Upon the Wet-Weight Basis; Sugar Percentages Upon the Dry-Weight Basis

Series	Moisture	Simple Sugars	Cane Sugar	Total Sugars
1: Untreated	**65.91**±0.067	**1.064**±0.027	**2.475**±0.039	**3.670**±0.015
2: Water	**68.62**±0.148	**1.042**±0.003	**2.208**±0.011	**3.367**±0.008
3: 1 per cent glucose	**68.24**±0.339	**1.236**±0.008	**2.576**±0.042	**3.948**±0.036
4: 2 per cent glucose	**70.02**±0.453	**1.362**±0.019	**3.536**±0.054	**5.084**±0.076
5: 5 per cent glucose	**66.34**±0.124	**1.459**±0.012	**5.204**±0.013	**6.937**±0.001
6: 10 per cent glucose	**64.62**±0.315	**2.874**±0.038	**8.473**±0.117	**11.794**±0.162
7: 25 per cent glucose	**59.83**±0.391	**8.565**±0.016	**9.593**±0.086	**18.663**±0.074

If the percentages of sugars in Series 2 are subtracted from those in Series 3-7, the percentages gained by the leaves from the sugar supplied are obtained. Now if the percentage increase in cane sugar is divided by the percentage increase in total sugars, the result is the percentage of glucose absorbed which is converted into cane sugar. The higher the percentage the greater the efficiency of the synthesis or manufacture of cane sugar, and this figure is hereafter called the "synthetic efficiency." The results of these calculations are presented in Table IV, which shows that increasing the concentration of glucose supplied from one to 10 per cent increased the gain in cane sugar from 0.3 per cent to 6 per cent, but increasing the concentration of glucose supplied from 10 to 25 per cent increased the gain in cane sugar from 6 to 7 per cent only. Increasing the concentration of glucose supplied from one to 10 per cent increased the gain in simple sugars from 0.2 per cent to 1.8 per cent, whereas increasing the concentration of glucose supplied from 10 to 25 per cent increased the gain in simple sugars from 1.8 per cent to 7.5 per cent. The same point is illustrated graphically in Fig. ~~1,~~ in which the slope of the curve for cane sugar is greater between one and 10 per cent glucose supplied than between 10 and 25 per cent, and the slope of the curve for simple sugars is less between one and 5 per cent than between 5 and 25 per cent.

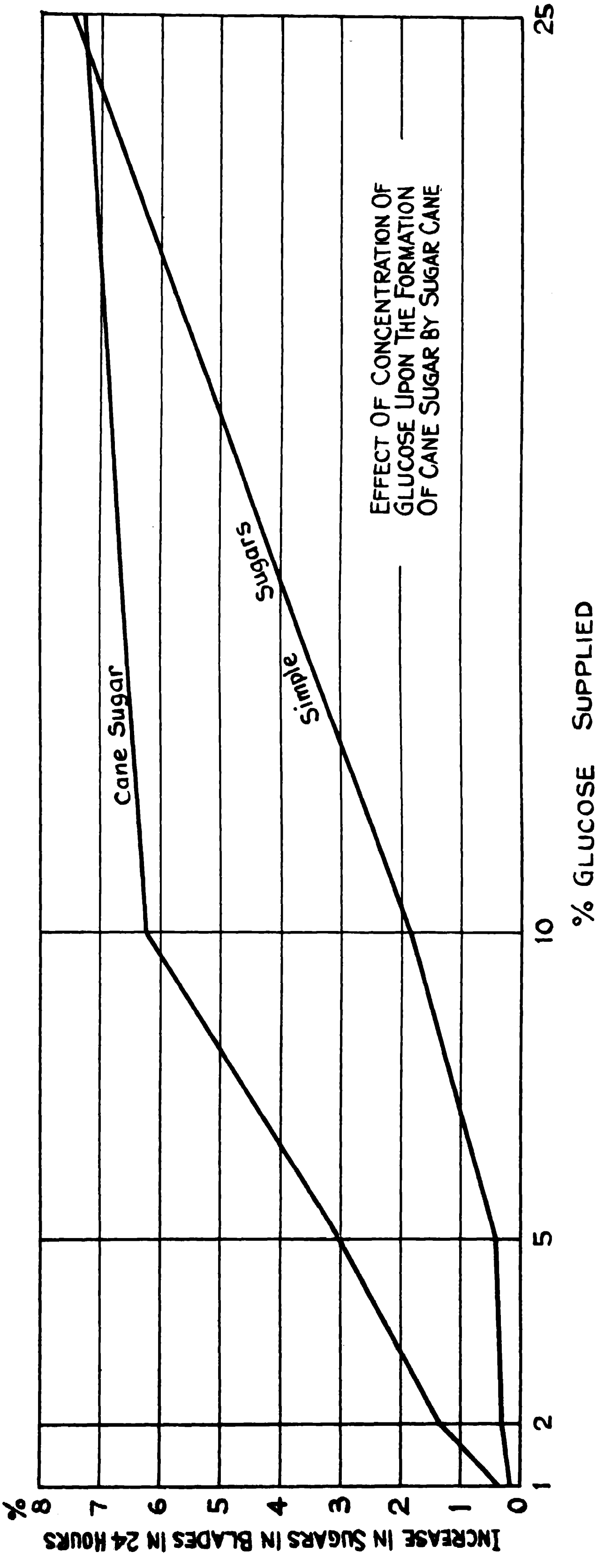

Effect Of Concentration Of Glucose Upon The Formation Of Cane Sugar By Sugar Cane
Cane Sugar
Simple Sugars
% Glucose Supplied
Increase In Sugars In Blades In 24 Hours
%
0 1 2 3 4 5 6 7 8
1 2 5 10 25

Fig. 1.

TABLE IV

Gains in Sugars, and Synthetic Efficiency, of Blades in Experiment 3; Percentages Expressed Upon the Dry-Weight Basis

Series	Simple Sugars	Cane Sugar	Total Sugars	Synthetic Efficiency
3: 1 per cent glucose............	0.194	0.368	0.581	63.33
4: 2 per cent glucose............	0.320	1.328	1.717	77.34
5: 5 per cent glucose............	0.417	2.996	3.570	83.92
6: 10 per cent glucose............	1.832	6.265	8.427	74.34
7: 25 per cent glucose............	7.523	7.385	15.296	48.28

The greater amount of gain in cane sugar was obtained at the lower concentration of glucose supplied, whereas the greater amount of gain in simple sugars was obtained at the higher concentrations of glucose supplied. When there was only a little glucose supplied, most of it was used in the formation of cane sugar; but when a greater amount of glucose was supplied, although more cane sugar was formed, there was a larger residue of simple sugars in the blade not used in the formation of cane sugar. Perhaps more of the glucose at the higher concentrations would have been converted into cane sugar if given sufficient time.

When the solution of glucose supplied was 25 per cent, the gain in simple sugars approximately equalled the gain in cane sugar. In other words, 48 per cent of the simple sugar absorbed was converted into cane sugar, or the synthetic efficiency was 48 per cent. Table IV shows that the synthetic efficiency varied with the concentration of glucose supplied, being greatest in a 5 per cent solution, in which 83 per cent of the sugar absorbed was converted into cane sugar. This figure illustrates the strength of the mechanism of sucrose synthesis in sugar cane. In the subsequent experiments only 5 per cent solutions of glucose or fructose were used, since the synthetic efficiency was greatest at that concentration.

Experiment 4. Effect of molasses:

Coincident with Experiment 3, a test was conducted to determine whether or not molasses could be used instead of glucose. Blades were kept in a 10 per cent solution of molasses for 24 hours, after which time the following percentages were obtained: moisture, 59.58 per cent; simple sugars, 1.559 per cent; cane sugar, 2.396 per cent; total sugars, 4.082 per cent. When these results are compared with those presented in Table III, the blades supplied with molasses are found to have had a gain in simple sugars comparable to that gained by the blades supplied with a 5 per cent solution of glucose, but no significant gain in cane sugar. The 10 per cent solution of molasses was found to be 2.58 per cent reducing substance. Therefore there was something in the molasses which inhibited the conversion of glucose into cane sugar. This experiment will be repeated using several concentrations of molasses.

Experiment 5. The effect of time upon the formation of sucrose from glucose:

The blades were placed in flasks at 8:30 a. m. September 15, with 100 cc. of a 5 per cent solution of glucose for each blade. There were 16 blades in each series, half of which were used for the determination of sugars reported in this paper and half for the determination of invertase to be reported later. The series were as follows:

1: Untreated (8:30 a. m.)
2: In dark 1 hour (9:30 a. m.)
3: In dark 2 hours (10:30 a. m.)
4: In dark 3 hours (11:30 a. m.)
5: In dark 5 hours (1:30 p. m.)
6: In dark 7 hours (3:30 p. m.)
7: In dark 11 hours (7:30 p. m.)
8: In dark 24 hours (8:30 a. m.)

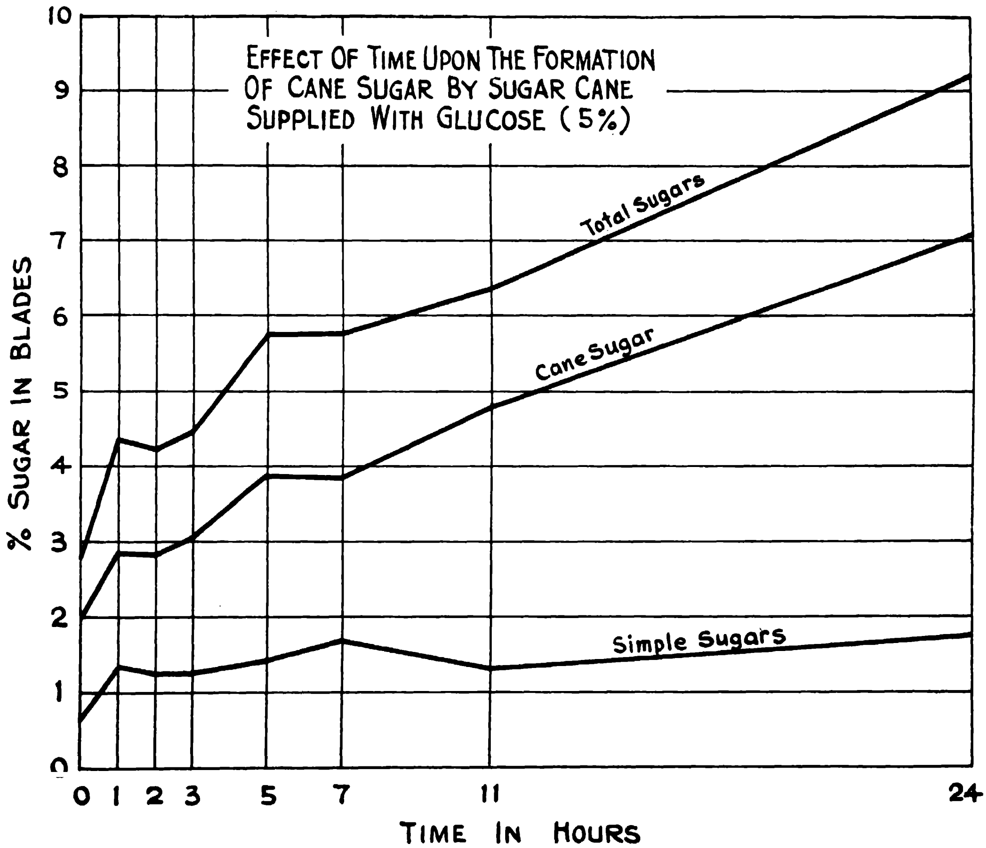


Fig. 2.

The results of the determinations of moisture and sugars are recorded in Table V and Fig. 2, which show that the greatest increase in percentage of simple sugars occurred during the first hour, after which time the percentage of simple sugars in the blades remained fairly uniform for 24 hours. The percentage of cane sugar also increased during the first hour, followed by an hour or so of no increase, and thereafter for 24 hours a fairly steady increase in cane sugar occurred.

TABLE V

Moisture and Sugar Percentages in Blades in Experiment 5; Moisture Percentages Expressed Upon the Wet-Weight Basis; Sugar Percentages Upon the Dry-Weight Basis

Series	Moisture	Simple Sugars	Cane Sugar	Total Sugars
1: Untreated	**64.54**±0.153	**0.649**±0.006	**1.986**±0.007	**2.739**±0.013
2: 1 hour	**68.84**±0.105	**1.353**±0.005	**2.855**±0.016	**4.358**±0.022
3: 2 hours	**67.34**±0.477	**1.239**±0.012	**2.841**±0.034	**4.230**±0.048
4: 3 hours	**67.97**±0.014	**1.254**±0.033	**3.038**±0.030	**4.453**±0.001
5: 5 hours	**67.38**±0.153	**1.425**±0.042	**3.894**±0.013	**5.524**±0.029
6: 7 hours	**66.58**	**1.674**±0.020	**3.861**±0.008	**5.738**±0.011
7: 11 hours	**66.33**±0.548	**1.314**±0.007	**4.795**±0.045	**6.360**±0.055
8: 24 hours	**66.78**±0.372	**1.769**±0.018	**7.060**±0.001	**9.202**±0.019

Experiment 6. The effect of time upon the formation of sucrose from fructose:

The blades were placed in the flasks containing their respective solutions at 8:30 a. m., September 17. The experiment was identical with Experiment 5, except that the sugar supplied was fructose instead of glucose. The fructose used in Series 2-8 was a 5 per cent solution prepared from the rootstalk of the ti plant by Dr. U. K. Das, to whom the author expresses grateful appreciation. The sugar used in Series 9 was chemically pure fructose supplied by the Pfanstiehl Chemical Company.

The results of the determinations of moisture and sugars, which are presented in Table VI and Fig. 3, are similar to those obtained in Experiment 5, using glucose. The blades supplied with fructose increased in percentage of simple sugars during the first hour, after which time their percentages of simple sugars remained

TABLE VI

Moisture and Sugar Percentages in Blades in Experiment 6; Moisture Percentages Expressed Upon the Wet-Weight Basis; Sugar Percentages Upon the Dry-Weight Basis

Series	Moisture	Simple Sugars	Cane Sugar	Total Sugars
1: Untreated	**68.05**±0.076	**0.819**±0.019	**2.178**±0.058	**3.112**±0.042
2: 1 hour	**67.18**±0.009	**1.241**±0.044	**2.604**±0.011	**3.983**±0.056
3: 2 hours	**66.45**±0.157	**1.284**±0.025	**2.591**±0.018	**4.012**±0.044
4: 3 hours	**67.40**±0.181	**1.272**±0.023	**2.616**±0.032	**4.026**±0.057
5: 5 hours	**66.66**±0.038	**1.211**±0.030	**2.992**±0.041	**4.361**±0.074
6: 7 hours	**67.01**±0.343	**1.327**±0.018	**3.629**±0.005	**5.148**±0.024
7: 11 hours	**68.59**±0.057	**1.586**±0.021	**5.527**±0.005	**7.404**±0.027
8: 24 hours	**68.21**	**1.618**±0.003	**7.122**±0.015	**9.115**±0.013
9: 24 hours (c. p. fructose)	**65.44**±0.157	**1.420**±0.030	**6.867**±0.024	**8.649**±0.005

fairly uniform for 24 hours. The percentage of cane sugar also increased during the first hour, after which there was no gain for two hours, followed by a steady gain throughout the remainder of the 24-hour period.

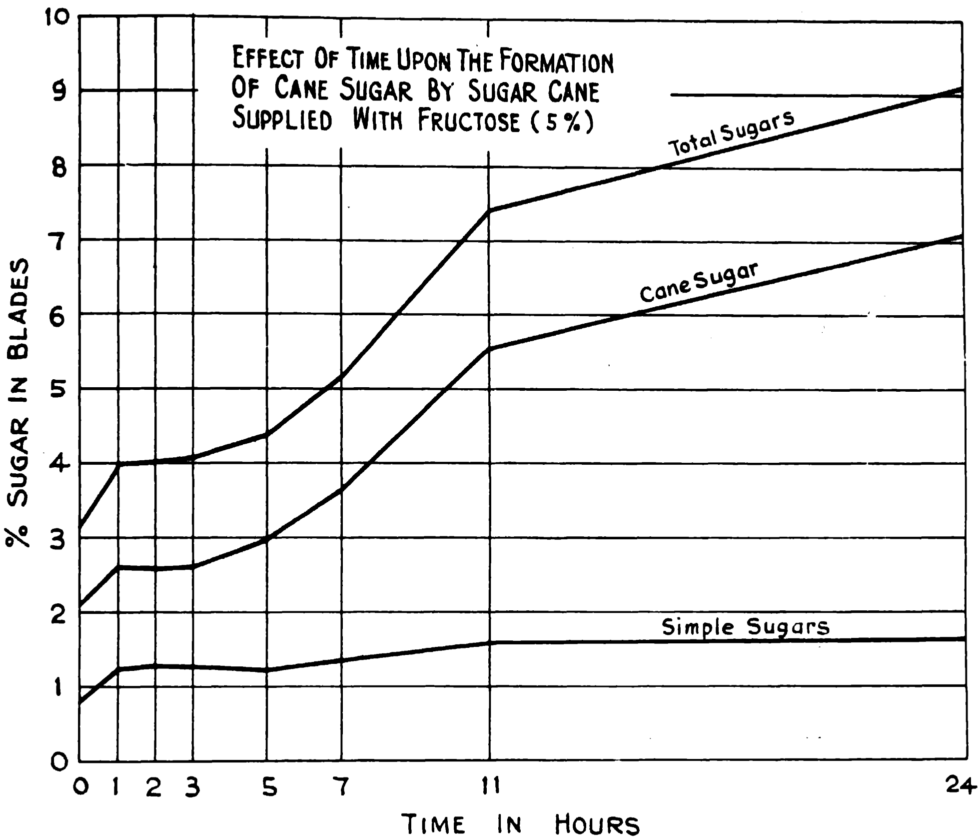


Fig. 3.

The results of Experiment 6 therefore confirm those of Experiment 5. Whichever simple sugar is supplied, whether glucose or fructose, it is the cane sugar which varies the most in concentration in the leaf.

Comparison of Series 8 and 9 (Table VI) shows that the fructose prepared from the rootstalk of the ti plant and the chemically pure fructose prepared by the Pfanstiehl Chemical Company were used equally well in the absorption of simple sugars and formation of cane sugar by the sugar cane plant.

Experiment 7. The formation of cane sugar does not require chlorophyll:

One albino stalk and one green stalk taken from the same plant of the variety POJ 2878 were cut early in the morning of August 6, 1936, at the Oahu Sugar Company, placed in a tin, and brought to the Enzyme Laboratory by J. P. Martin. The albino stalk bore only three leaves. The upper and lower leaves were placed in the dark, and the middle leaf was used as the untreated series. The series were as follows:

1: Albino untreated
2: Green untreated
3: Albino in sugar
4: Green in sugar

Series 3 and 4 received 100 cc. of a 10 per cent solution of glucose per blade, and were placed in the dark at 11:30 a.m. August 6 where they remained for 24 hours.

The results of the determinations of moisture and sugars are recorded in Table VII, which shows that the albino leaf increased in cane sugar from 0.576 per cent to 7.955 per cent or a difference of 7.379 per cent, while the green leaf increased in cane sugar from 2.500 per cent to 9.741 per cent or a difference of 7.241 per cent. Therefore, when supplied with glucose an albino leaf can make cane sugar as well as a green leaf.

TABLE VII

Moisture and Sugar Percentages in Blades in Experiment 7; Moisture Percentages Expressed Upon the Wet-Weight Basis; Sugar Percentages Upon the Dry-Weight Basis

Series	Moisture	Simple Sugars	Cane Sugar	Total Sugars
Untreated				
1: Albino	79.87	2.089	0.576	2.695
2: Green	74.45±0.734	1.559±0.009	2.500±0.004	4.191±0.004
In Sugar				
3: Albino	75.03±0.548	4.735±0.025	7.955±0.166	13.109±0.200
4: Green	74.82±0.210	5.510±0.053	9.741±0.085	15.764±0.036

Discussion

The manufacture of cane sugar from simple sugars, the role of the enzyme invertase, and the question of which sugar is formed first in photosynthesis are closely related problems, for, if cane sugar is the primary sugar in photosynthesis, then the role of invertase may be only hydrolytic and it is possible that all of the cane sugar present in the sugar cane plant is formed without using glucose and fructose; whereas, if the simple sugars are formed first, there must be some mechanism for their conversion into cane sugar, and that mechanism might be the enzyme invertase.

Definite evidence that the leaf of the sugar cane plant possesses a mechanism for the conversion of glucose and fructose into cane sugar has been presented in Tables I, III, V, VI, and VII and in Figs. 1-3. The fact that the sugar cane leaf can manufacture cane sugar from simple sugar when artificially supplied with glucose and fructose does not necessarily prove that that is the natural method of formation of sucrose, but is strong presumptive evidence.

The fact that neither light nor chlorophyll is necessary for the formation of sucrose shows that cane sugar can be made by a process other than photosynthesis but does not prove that cane sugar is always made by a process other than photosynthesis. This manufacture of cane sugar takes place against a gradient, i.e. there is always less simple sugar than cane sugar in the blades, according to Tables I, III, V, VI, and Table VII with the exception ~~of the~~ "albino-untreated."

Therefore, the argument that leaves cannot manufacture cane sugar from the simple sugars in nature because leaves contain less simple sugar than cane sugar, is not founded upon fact.

The formation of cane sugar from simple sugars in blades containing less simple sugars than cane sugar is explainable by the fact that there was a high head of glucose in the external solution, comparable to the hypothesized formation of simple sugars in the process of photosynthesis.

The mechanism for producing cane sugar from simple sugars was strong enough to handle nearly all of the glucose absorbed when supplied at the lower concentrations, according to Table III and Fig. 1. This ability may be the same whether the simple sugar is supplied artificially as in these experiments or naturally as in photosynthesis. This statement is in agreement with the viewpoint that the reason simple sugars in the blades of the sugar cane plant fluctuate by day less than cane sugar does is because the simple sugars are formed first in photosynthesis and are only transitory in occurrence while cane sugar is a storage form.

The curves presented in Figs. 2 and 3 closely resemble those obtained in the studies of the fluctuations of sugars in the blades of the sugar cane plant during the day and the night (3). In both studies the curves for simple sugars are flatter than those for cane sugar, indicating considerably less fluctuation in simple sugar content than in cane sugar content. The difference between this experiment and photosynthesis is that here we know we have a simple sugar first, whereas in photosynthesis that is a question. The fact that similar types of curves are formed both in photosynthesis and in artificial feeding in the dark suggests that in both processes glucose is used up so rapidly that there is not enough left to accumulate, a theory already proposed by several physiologists for photosynthesis.

The results presented in this paper are in accord with the viewpoint that the simple sugars are formed first in photosynthesis and are then converted into cane sugar. The formation of cane sugar does not require light, as shown by these experiments. The manufacture of cane sugar in nature stops at nightfall, not because light is required for its immediate formation, but because without light the production of simple sugars by photosynthesis ceases. When a supply of simple sugars is furnished without photosynthesis, the formation of cane sugar proceeds readily in the dark.

Cane sugar is, of course, a double sugar yielding upon digestion equal parts of glucose and fructose. The question arises as to how the blade can form cane sugar when supplied with glucose or fructose alone. Since this formation actually occurs, according to the results presented in this paper, the conclusion seems inevitable that the blade of the sugar cane plant possesses a mechanism for the interconversion of glucose and fructose. We are not concerned here with the chemistry of this mechanism, which has been studied in other plants and in vitro by numerous investigators, but merely with the fact that it does take place.

When supplied with glucose, the blades reached 7.060 per cent cane sugar, as shown in Table V; when supplied with fructose, the blades reached 7.122 per cent cane sugar, as shown in Table VI. Therefore the ease of forming glucose from fructose equals the ease of forming fructose from glucose. This fact may be of fundamental importance in the sugar cane plant, as it may be responsible for the chief storage carbohydrate being cane sugar rather than starch as in the corn plant, or inulin as in the ti plant.

The necessity for the formation of glucose from fructose and vice versa, in the blades supplied with only one simple sugar, may explain the lag in the formation of cane sugar after the first hour, illustrated in Figs. 2 and 3. In the experiment in which glucose alone was supplied, perhaps the little fructose already present within the blade was used during the first hour, and during the second hour enough fructose may have been formed from the glucose absorbed to permit further formation of cane sugar. If this explanation is correct, there should be no such lag in the manufacture of cane sugar when both glucose and fructose are supplied in equal amounts, a point to be determined in another experiment.

The fructose immediately formed by the digestion of cane sugar is unstable, changing very quickly into a more stable form. The cane sugar molecule requires the unstable, highly reactive form of fructose and its absence hinders or prevents the synthesis of cane sugar in vitro and is often presented as evidence that the action of the enzyme invertase cannot be reversible. The results herein presented show that a sugar hydrolyzable by invertase is formed by the blades of the sugar cane plant when supplied with either glucose or fructose. Evidently the blades of the sugar cane plant are not only able to convert glucose to fructose, but also to convert the stable form of fructose into the unstable form of the sugar necessary for the manufacture of sucrose. The possible importance of phosphorus in the formation of glucose-phosphate as an intermediate step in these processes will be considered in another experiment.

The results reported herein are in agreement with those obtained by Virtanen and Nordlund (7), with red clover and wheat, both in demonstrating a formation of cane sugar from simple sugars and in indicating a mutual interconversion of glucose and fructose. Our results are also in accord with the further work of Nurmia (née Norlund) (5, 6), using wheat, oats, clover, and horse bean. Recalculation of the data presented by Nurmia (5) shows that the leaves of the horse bean, when placed in a 10 per cent solution of glucose for 24 hours, had a synthetic efficiency of 38 per cent, and when placed in a 10 per cent solution of fructose for 24 hours, the leaves had a synthetic efficiency of 48 per cent. Since the blades of the sugar cane plant in a 10 per cent solution of glucose for 24 hours possessed a synthetic efficiency of 74 per cent, according to Table IV, we may conclude that the sugar cane leaf possesses a much more efficient mechanism for the manufacture of cane sugar than is found in the leaf of the horse bean. This difference should be expected, since the natural storage food is cane sugar in the sugar cane plant but not in the horse bean, in which the natural storage foods are protein, fat, and starch.

Coelingh and Koningsberger (1) found that the leaf of sugar cane of the variety POJ 2878 can form starch in the dark from a sugar solution, using maltose, cane sugar, glucose and fructose. The formation of starch, and the use of sugars other than glucose and fructose, have not yet been studied in this investigation.

Now that it has been determined that the blade of the sugar cane plant possesses a highly efficient mechanism for the production of cane sugar from the simple sugars, glucose and fructose, the next step is to determine if possible whether or not this mechanism is the enzyme invertase. This point is now being studied and the results will be reported later. Other experiments not included in this paper have shown that neither sulphur nor magnesium is needed for the conversion of the

simple sugars to cane sugar. The effects of external conditions upon the efficiency of synthesis should be determined, also the question as to what other organs of the sugar cane plant are able to conduct the synthesis.

Summary

1. The leaf blade of the sugar cane plant can manufacture cane sugar when supplied with the simple sugars, glucose and fructose.
2. This process takes place in the dark.
3. It does not require chlorophyll.
4. There is always a higher percentage of cane sugar than of simple sugars in the blades, no matter what the concentration of glucose supplied, within the limits of 1-25 per cent.
5. The synthesis is most efficient when the blades are supplied with a 5 per cent solution of glucose, in which 83 per cent of the sugar absorbed is converted into cane sugar in 24 hours.
6. Since the synthesis takes place when the blades are supplied with glucose or fructose alone, and since cane sugar contains both, a transformation from glucose to fructose and from fructose to glucose occurs in the blades of the sugar cane plant.
7. The interconversion of glucose and fructose occurs equally well whichever sugar is supplied.
8. The cane sugar fluctuates more widely than the simple sugars in the blades supplied with glucose or fructose.
9. The results herein reported are thus in agreement with the viewpoint that the simple sugars are formed first in photosynthesis and are then converted into cane sugar.

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The writer desires especially to thank Dr. H. L. Lyon for his inspiration and encouragement in facilitating this research.

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The Availability of the Principal Nutrients in a Soil During the Crop-Growth Period

By Ralph J. Borden

The general practice, when sampling cane field soils for the analysis and determination of their available nutrient status so that fertilizer recommendations can be more intelligently made, is to collect the soil sample either before the plant crop is fertilized, or in the interim between harvest and the first fertilization of the succeeding ratoon. Hence, by far the greater part of the analytical data that we have previously recorded is concerned with a measure of the fertility status that exists in the soil at the beginning (or the end) of the cropping period.

The desire to know more about the availability of the three principal plant foods in the soil throughout the progress of the growth of a crop of cane, led to plans for securing a continuous record of these nutrients by both chemical and biological analyses of soil samples taken from the active root zone twice a month during the entire growth period.

Through the cooperation of Waialua Agricultural Company an apparently uniform area in Field Helemano 5A was chosen, where a ratoon crop of H 109 was being started on November 16, 1934. The area was divided into 2 sections, each comprising three adjacent watercourse plots occupying approximately one-half acre; the 2 sections were separated by a single watercourse plot. Within each of these 2 sections (A and B) 12 sampling points were definitely established. The soil that was submitted from each section for analysis at each date of sampling was a composite sample made up by taking 2 borings with a 4-inch soil auger to a depth of 12 inches, in the sides of the cane line adjoining each of the 12 sampling points, thus there are 24 borings for each composite soil sample. The auger holes were filled up and marked with a wire pin and successive soil samples were always taken in the cane line within 12 inches of the previous borings.

The first samples were collected on November 17, 1934 and thereafter the areas were sampled on or about the 15th and 30th of each month to and including August 30, 1936.

In order to get a general idea of the natural fertility status in this area without having to contend with a complication that would be introduced if commercial fertilizer were applied, the crop was allowed to go without any fertilization until March 12, 1935. Hence we were able to collect the first 8 samples from cane rows which had not been fertilized.

Adequate and similar amounts of irrigation and weed control were given to both sections. Commercial fertilizer applications were carefully made by hand to the cane rows in each section, according to the following plan:

Sec.	3/12 1935 lb K_2O	3/20 1935 lb N	4/9 1935 lb P_2O_5	5/15 1935 lb N	6/15 1935 lb N	7/15 1935 lb N	9/16 1935 lb N	3/16 1936 lb N	Totals N	P_2O_5	K_2O
A	50	40	200	40	0	40	40	40	200*	200	50
B	50	90	200	0	90	0	0	60	240	200	50

*Due to the heavy cane growth and trash, a final application of 40 pounds of nitrogen scheduled for the "A" section in April 1936 was omitted.

Chemical analyses of these periodic soil samples have been made in our Chemistry department. These have included determinations of pH, phosphoric acid, potash, ammoniacal and nitrate nitrogen by the rapid chemical methods (hereafter referred to as R.C.M.), and of the percentage of total and of water soluble nitrogen by the Kjeldahl method. The phosphate fixation index was also secured.

Biological analyses of these same soil samples were made in our Mitcherlich department. These included determinations of the indicated amounts of available nitrogen, phosphoric acid and potash.

The results of the many analyses have furnished us with an array of figures which are offered in Table II. All percentage figures received from the analyst have been calculated to pounds per acre-foot of soil (2,500,000 pounds) and are tabulated as such to facilitate comparisons with the Mitscherlich results.

In presenting the data, we have averaged the 2 samples that were taken each month, and have used this average monthly figure in building up the bar-graphs which follow, in order to show the general trends without confusing the reader by presenting all of the variations that were found in the successive samples. This procedure should not, however, let us lose sight of the fact that we may find quite sizeable variations in the analytical results from soil samples, even when such samples have been reliably taken from almost the same spots in the field only some 2 weeks apart. Undoubtedly a soil sampling error contributes to a large part of this variation, but it is not altogether improbable that it is also influenced by conditions that are the result of differences between the uptake of nutrients by the growing plants and the total available nutrient supply, natural and added, in the soil. A general idea of the range of these variations that existed is shown as pounds per acre-foot of soil as follows:

	Section A	Section B
Range of available nitrogen:		
By R.C.M. analysis................	15 to 98 ℔	13 to 125 ℔
By Mitscherlich test................	41 to 131 ℔	42 to 253 ℔
Range of available phosphoric acid:		
By R.C.M. analysis................	70 to 550 ℔	30 to 400 ℔
By Mitscherlich test................	44 to 298 ℔	33 to 196 ℔
Range of available potash:		
By R.C.M analysis................	75 to 275 ℔	75 to 300 ℔
By Mitscherlich test................	281 to 844 ℔	367 to 873 ℔

In Figs. 1 and 2, we show the monthly variation of available nitrogen, determined by the Mitscherlich test and R.C.M. respectively, as it occurred in both Sections A and B. During the first 4 months, before any fertilizer was applied, there was but little change in the status of available nitrogen. With the application of ammonium sulphate in March 1935, there was an immediate increase of nitrogen found in the soil, especially from Section B, which had received the heavier application. This was chiefly ammonia nitrogen (from the ammonium sulphate). The manner and speed with which it was nitrified and removed from the soil is indicated in Fig. 3—within a period of 6 weeks it had entirely disappeared. The larger nitrogen fertilizer applications at later dates were similarly effective in increasing the available nitrogen supply of the soil, but for a very short period only.

The low point for nitrogen in the soil was reached in January and February, 1936, and was still apparent when the spring dressing was applied in March.

There was an excellent correlation between the Mitscherlich results and those secured by the rapid chemical methods (R.C.M.), although the Mitscherlich results were in general about 3 times larger. The only significant difference between the average nitrogen status of the 2 sections was in the amount of total nitrogen; this was significantly greater in Section A. The more interesting of the nitrogen data are summarized in Table I.

FIG. 1

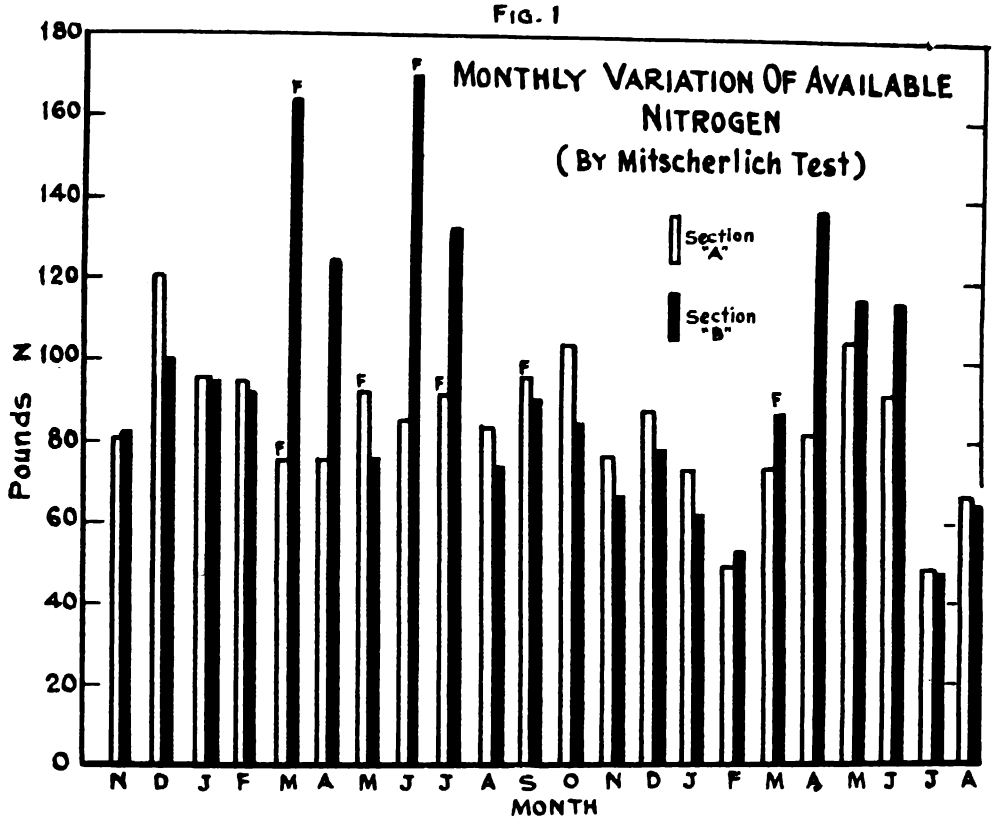
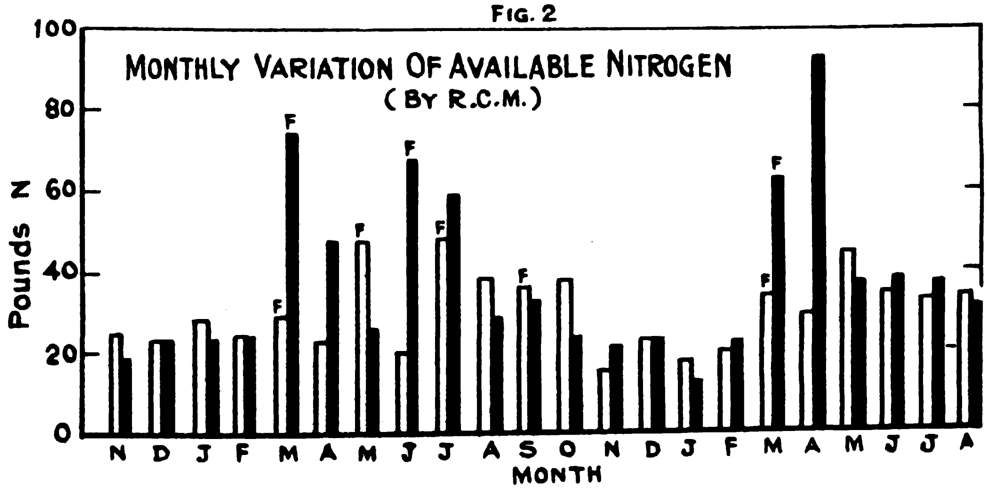


FIG. 2



F = Fertilized with Nitrogen

FIG. 3

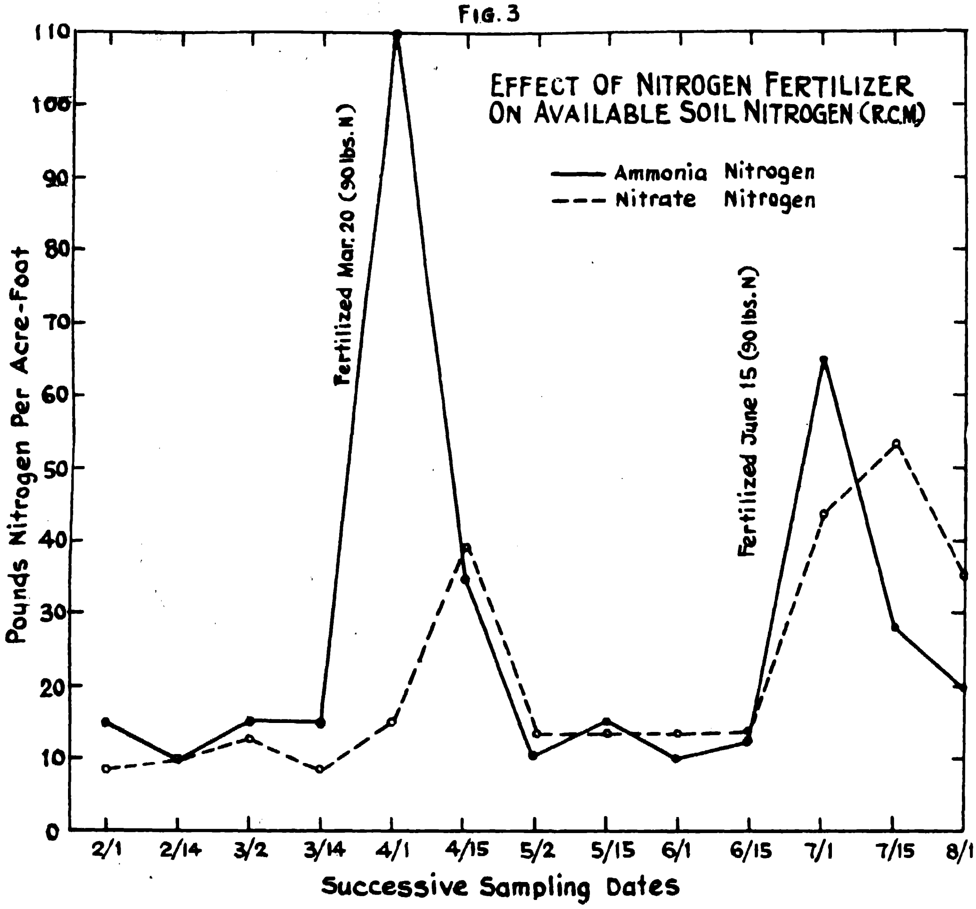


TABLE I

Summary of Pertinent Nitrogen Data

	Section A*	Section B*
1. Average lb nitrogen per acre-foot, during 22 months:		
By R.C.M.	34	42†
By Kjeldahl (water sol.)	35	41†
By Mitscherlich	97	119†
By Kjeldahl (total)	5777	5637‡
2. Percentage of total nitrogen:		
Available by Mitscherlich	1.68%	2.11%
Water soluble (Kjeldahl)	.60	.73
Water soluble (R.C.M.)	.59	.75
3. Correlation coefficients:		
Between Mitscherlich and (R.C.M.)	+.90±.020	+.88±.023
Between R.C.M. and Water sol. (Kjeldahl)	+.53±.074	+.77±.041
4. Correlation between Section A and Section B:		
For R.C.M. nitrogen	+.79±.039	

* Section A—43 samples Section B—44 samples
† Difference not significant
‡ Difference significant

The monthly variation in available potash is shown in Fig. 4. The steady increase in available potash that is apparent at the start of the crop before the potash fertilizer was applied, may indicate that the withdrawal by the growing crop at this age and time was slower than the rate at which the soil potash was being made available; hence it accumulated. The influence of the potash fertilization is shown in the March-April analyses. The drop in potash that is noticed in the first summer is probably due to the heavy demands made on potash by the crop which was then in its "boom" stage. The reason for a slight increase in August-September-October is speculative.

The relatively low amount of available potash in the soil during the second season is thought to be due to the heavy drain that has by that time been made upon it by the crop. Since this condition may be the result of a luxury consumption of potash, and at any rate since it is generally believed that sufficient potash has already been taken up by the cane plant and can be translocated and re-utilized within the plant system until the crop is harvested, such low available potash in the soil at this time may be without any real practical significance.

The similarity of the available potash status in the 2 sections (A and B) is indicated by their coefficient of correlation: $+.80 \pm .037$. The similarity between the Mitscherlich results and the results by R.C.M. for potash is not as consistent as the nitrogen comparisons were, but the relationship is nevertheless a definitely positive one, as will be indicated by these coefficients of correlation: $+.65 \pm .059$ for Section "A," and $+.50 \pm .076$ for Section "B."

In Fig. 5, the monthly picture of the supply of available phosphoric acid in the soil of a field which has been fertilized with phosphates is full of interest for the student of soil sampling for fertility studies. An even better picture is obtained from an inspection of the individual items in Table II in the column headed "P_2O_5-R.C.M." Although the soil sample that was analyzed was a composite of 24 auger borings taken from the cane row, and at each successive sampling date the new borings were each made within 12 inches of the previous bore, the variation in results from successive samplings is large enough to cause a respectful pause when it is being interpreted.

The field in which this study was carried on was one with a ratoon crop; this indicates that phosphate fertilizer had been applied on these cane rows in the previous crop, in fact the field records show that 250 pounds of P_2O_5 had thus been applied. Since we know that this soil has the power to "fix" this applied phosphate, and as it is unlikely that the previous crop actually took even half of this amount out of the soil, it is obvious that some of the phosphate that was applied to the previous crop remained pretty close to where it was placed, and was there when we started to sample for this present crop. Hence, knowing how unlikely it is that phosphate fertilizer is "thrown" uniformly on the cane row, it is not difficult to explain such variations in results from soil samples taken before fertilizing the present crop at successive semi-monthly periods, as these from:

Section A: 100 - 150 - 100 - 300 - 70 - 150, and from
Section B: 100 - 150 - 30 - 150 - 100 - 150 pounds per acre.

Fig. 4

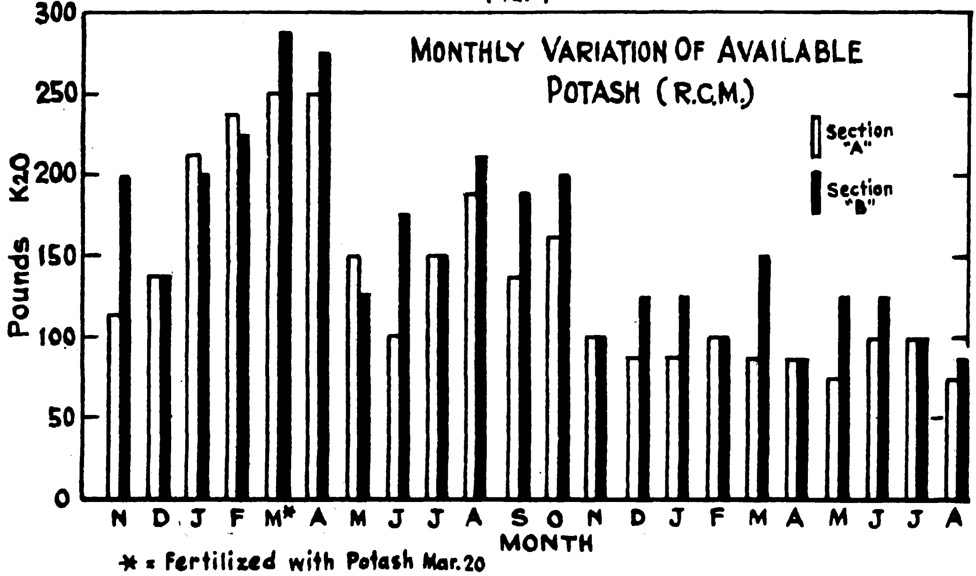
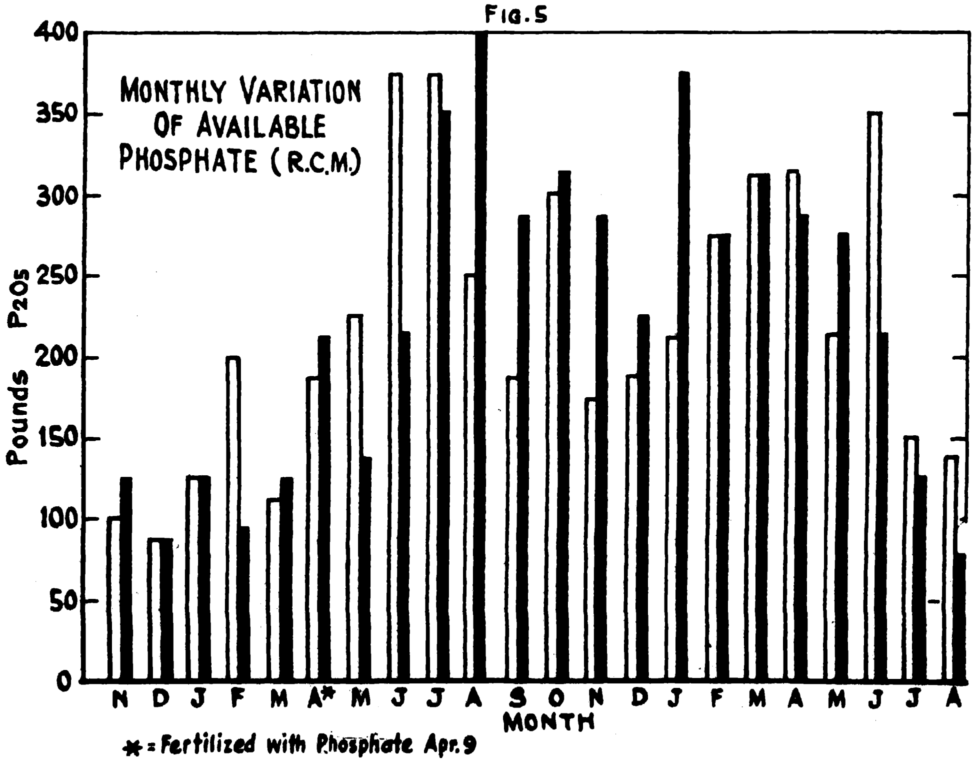

Monthly Variation of Available Potash (R.C.M.)
Section "A"
Section "B"
Pounds K2O
300
250
200
150
100
50
0
N D J F M* A M J J A S O N D J F M A M J J A
MONTH
* = Fertilized with Potash Mar. 20

Fig. 5


Monthly Variation of Available Phosphate (R.C.M.)
Pounds P2O5
400
350
300
250
200
150
100
50
0
N D J F M A* M J J A S O N D J F M A M J J A
MONTH
* = Fertilized with Phosphate Apr. 9

A similar condition is found throughout the growth of this crop we studied, even after we had been especially careful to apply the superphosphate to the cane rows of both Sections A and B in such a way as we thought would tend to reduce this variation in results of soil samples taken later on. And we find such variations in pounds of P_2O_5 (R.C.M.) for successive samplings after fertilization as indicated by these 4 examples, taken at random from Table II:

1. 125 - 200 - 250 - 550 - 200 - 400 - 350
2. 150 - 175 - 250 - 175 - 375 - 175 - 350
3. 125 - 300 - 350 - 350 - 400 - 400 - 225
4. 400 - 400 - 175 - 300 - 150 - 350 - 400

Fortunately these figures are all believed to represent an adequate supply of phosphate and hence the variations in this case may not have a practical meaning, but in the case of the samples taken at the start of the crop, that taken in Section B on February 1, showing 150 pounds P_2O_5 would indicate no real need of phosphate fertilization for this soil, while the next sample taken from the same place 2 weeks later showing only 30 pounds P_2O_5 would definitely indicate a real phosphate deficiency; similarly from Section A, we have a sample taken on March 2 showing 300 pounds of P_2O_5 which is certainly an adequate supply, but on March 14 when only 70 pounds were found, an inadequate supply is indicated; yet 2 weeks later before any phosphate fertilizer had been applied, this apparent deficiency disappeared.

The general trend shown in Fig. 5 is that the available phosphate supply was increased when the phosphate fertilizer was applied in April, and that it remained at a fairly high level thereafter. There was apparently a reduced supply in the second winter, and the supply had quite definitely fallen off in the last 2 months before harvest while the area was being "dried-off for ripening."

The comparative similarity of the phosphate status (R.C.M.) in Sections A and B is indicated by the correlation coefficient of $+.51 \pm .076$; although this is definitely positive, undoubtedly the "sampling error" was an influence.

A correlation coefficient of $+.78 \pm .040$ from Section A and of $+.81 \pm .035$ from Section B indicates the very favorable relationship that exists between the results for phosphate as secured by the Mitscherlich and the R.C.M. analyses of soil samples.

Altogether, the results secured have given us a better idea of: (a) How the availability of nitrogen, phosphoric acid, and potash in the cropped soil is being largely influenced by applications of fertilizers and by crop uptake; (b) The speed with which ammonium fertilizer may be utilized (we assume leaching to be negligible); (c) The difference between the supply of available potash in the cropped soil during the early development of the crop and in its second year of growth; (d) The definite build-up of the soil phosphate supply by fertilization; and (e) The difficulties concerned with securing "true" soil samples for fertility analyses from areas that have been fertilized (especially with phosphates) unless the real conditions resulting therefrom are appreciated and recognized.

TABLE II

Section A

Date	Fertilizer Applied	Pounds per Acre-Foot of Soil* Phosphate (P_2O_5) Mitsch.	Phosphate (P_2O_5) R.C.M.	Potash (K_2O) Mitsch.	Potash (K_2O) R.C.M.	Nitrogen (N) Mitsch.	Nitrogen (N) R.C.M.	Water Sol.	Total Kjel-dahl	pH	P_2O_5 Fixa-tion
Nov. 17, 1934		52	100	520	100	74	30	30	5775	6.4	35
Dec. 3		56	100	564	125	88	20	43	5725	6.6	40
Dec. 17		44	100	518	150	111	23	54	5900	6.2	35
Jan. 2, 1935		63	70	484	125	131	23	28	5925	6.6	40
Jan. 16		86	100	510	150	104	25	40	5650	6.2	35
Feb. 1		48	150	652	275	88	33	28	5650	6.4	40
Feb. 14		60	100	545	225	92	20	10	6000	6.5	40
Mar. 2	50 lbs. K_2O	97	300	1094†	250	97	28	10	5575	6.4	45
Mar. 14	40 lbs. N	64	70	844	250	78	23	10	5775	6.4	40
Apr. 1	200 lbs. P_2O_5	178	150	585	250	73	35	38	6025	6.6	35
Apr. 15		193	250	804	250	88	30	40	5825	6.4	45
May 2		94	125	685	250	64	16	35	5950	6.1	40
May 15	40 lbs. N	108	200	614	150	76	28	40	5900	6.4	40
June 1		196	250	600	150	107	65	54	6025	6.6	35
June 15		298	550	792	100	85	21	35	5850	6.1	30
July 1		135	200	665	100	88	20	23	5750	6.3	35
July 15	40 lbs. N	194	400	699	150	73	38	33	5725	6.2	35
Aug. 1		218	350	671	150	108	58	35	5850	6.0	30
Aug. 15		131	250	522	250	637**	203**	73**	6300	5.8	40
Aug. 31		133	250	474	125	84	38	38	5975	5.8	35
Sept. 16	40 lbs. N	59	200	452	125	88	28	33	5600	6.1	30
Sept. 30		75	175	467	150	104	43	58	5700	6.0	45
Oct. 15		133	300	557	225	106	40	45	5575	6.5	50
Nov. 2		133	300	377	100	102	33	38	5425	6.2	50
Nov. 18		145	...	437	...	80	...	...	....	...	..
Nov. 30		98	175	351	100	75	15	18	5575	6.0	45
Dec. 14		81	150	299	100	90	23	23	5825	6.6	45
Jan. 2, 1936		124	175	281	75	87	23	43	5775	6.7	45
Jan. 15		133	250	360	75	83	15	20	5925	6.8	50
Feb. 8		130	175	372	100	62	18	45	5575	6.0	40
Feb. 15		181	375	417	75	58	23	25	5900	6.2	45
Mar. 2		96	175	429	125	42	16	15	6100	6.2	50
Mar. 16	40 lbs. N	149	350	542	100	79	15	20	5800	6.2	50
Mar. 31		124	275	437	75	68	53	49	6100	6.6	50
Apr. 14		253	350	655	100	82	25	50	5650	6.0	45
May 1		221	275	418	—75	82	33	49	5725	6.0	50
May 15		144	175	417	—75	92	63	98	6000	6.0	..
June 1		204	250	510	—75	118	25	27	6075	6.3	50
June 15		176	350	447	100	101	23	38	5850	6.0	65
July 2		188	350	399	100	83	45	18	6250	6.1	50
July 16		198	150	511	100	42	35	25	5175	6.3	40
Aug. 1		121	150	462	100	56	30	18	5175	6.0	40
Aug. 15		104	150	374	75	93	35	31	5600	6.0	45
Aug. 30		120	125	324	75	41	30	20	4900	6.3	45

* From chemical analyses:
Pounds per acre-foot = p.p.m. x 2.5.
From Mitscherlich analyses:
Pounds per acre-foot obtained direct from proper use in Mitscherlich formula.
** Undoubtedly contaminated by nitrogen.
† Probably in error.

NOTE: The heavy lines in Table II separate the analyses of samples taken respectively before and after the indicated fertilizer was applied.

Section B

Date	Fertilizer Applied	Pounds per Acre-Foot of Soil* — Phosphate (P_2O_5) Mitsch.	R.C.M.	Potash (K_2O) Mitsch.	R.C.M.	Nitrogen (N) Mitsch.	R.C.M.	Water Sol.	Total Kjel-dahl	pH	P_2O_5 Fixa-tion
Nov. 17, 1934		33	100	645	250	76	18	18	5400	6.4	35
Dec. 3		63	150	564	150	88	20	23	5275	6.6	40
Dec. 17		35	100	665	125	90	23	28	5650	6.1	35
Jan. 2, 1935		84	70	578	150	109	23	30	5500	6.5	40
Jan. 16		89	100	783	150	100	23	28	5225	6.4	35
Feb. 1		78	150	666	250	89	23	28	5225	6.4	40
Feb. 14		42	30	533	200	91	20	10	5675	6.5	40
Mar. 2	50 lbs. K_2O	101	150	851	250	92	28	18	5625	6.4	45
Mar. 14	90 lbs. N	84	100	708	300	72	23	25	5800	6.4	40
Apr. 1	200 lbs. P_2O_5	151	150	873	275	253	125	45	5975	6.5	35
Apr. 15		151	300	634	300	167	73	60	5725	6.4	45
May 2		101	125	756	250	83	23	30	5850	6.4	40
May 15		79	150	618	150	86	28	43	6050	6.3	40
June 1		94	125	655	100	66	23	35	6000	6.8	40
June 15	90 lbs. N	114	125	699	150	98	25	30	5650	6.2	40
July 1		154	300	616	200	241	108	65	5800	6.1	40
July 15		160	350	826	150	156	63	70	5775	6.1	40
Aug. 1		172	350	495	150	107	55	48	5725	6.2	35
Aug. 15		156	400	663	300	1085**	253**	118**	5925	5.9	45
Aug. 31		128	400	792	125	74	28	45	5750	5.9	45
Sept. 16		132	225	608	125	87	20	33	6050	6.2	40
Sept. 30		143	350	583	250	94	43	56	5275	6.0	45
Oct. 15		104	225	729	300	90	23	28	5250	6.7	50
Nov. 2		118	400	533	100	81	23	43	5275	6.2	45
Nov. 18		177	400	552	100	76	23	35	5400	6.2	45
Nov. 30		68	175	567	100	57	18	28	5625	6.2	50
Dec. 14		102	300	417	150	86	25	35	5750	6.4	50
Jan. 2, 1936		86	150	472	100	72	21	45	5625	6.7	45
Jan. 15		168	350	515	150	70	13	23	5525	6.6	50
Feb. 8		180	400	414	100	53	13	38	5475	6.2	40
Feb. 15		185	400	654	75	46	25	20	5875	6.2	40
Mar. 2		105	150	471	150	60	18	18	6100	6.0	50
Mar. 16	60 lbs. N	147	300	702	150	75	25	25	5775	6.1	55
Mar. 31		138	325	503	150	100	98	60	6000	6.6	50
Apr. 14		196	375	591	100	175	98	98	5650	5.9	50
May 1		113	200	537	75	101	85	73	5725	6.0	50
May 15		188	275	506	150	129	48	100	6000	6.2	50
June 1		172	275	623	100	103	25	30	6000	6.4	55
June 15		135	250	560	125	160	43	48	5775	6.1	65
July 2		119	175	513	125	71	35	30	5825	6.0	55
July 16		142	150	511	100	42	40	38	5175	6.0	45
Aug. 1		107	100	554	100	53	35	20	5050	6.2	55
Aug. 15		89	125	367	100	86	30	20	5325	6.2	50
Aug. 30		40	30	456	75	43	33	23	4900	6.1	50

* From chemical analyses:
Pounds per acre-foot = p.p.m. x 2.5.
From Mitscherlich analyses:
Pounds per acre-foot obtained direct from proper use in Mitscherlich formula.
** Undoubtedly contaminated by nitrogen.
† Probably in error.

NOTE: The heavy lines in Table II separate the analyses of samples taken respectively before and after the indicated fertilizer was applied.

West African Notes

By R. H. Van Zwaluwenburg

A steamy-hot rain forest, roughly 100 miles wide, runs along the west coast of Africa for some 1500 miles, from the western shoulder of the continent to Cameroons Mountain, where it widens southward and continues east into Uganda. Believed to be the home of the group of insects to which the Mediterranean fruit fly belongs, the forested belt of West Africa was chosen, under one of the Hawaiian sugar processing-tax projects of the A. A. A., as a source from which to get more parasites to improve the natural control of the Mediterranean fruit fly and of the melon fly in

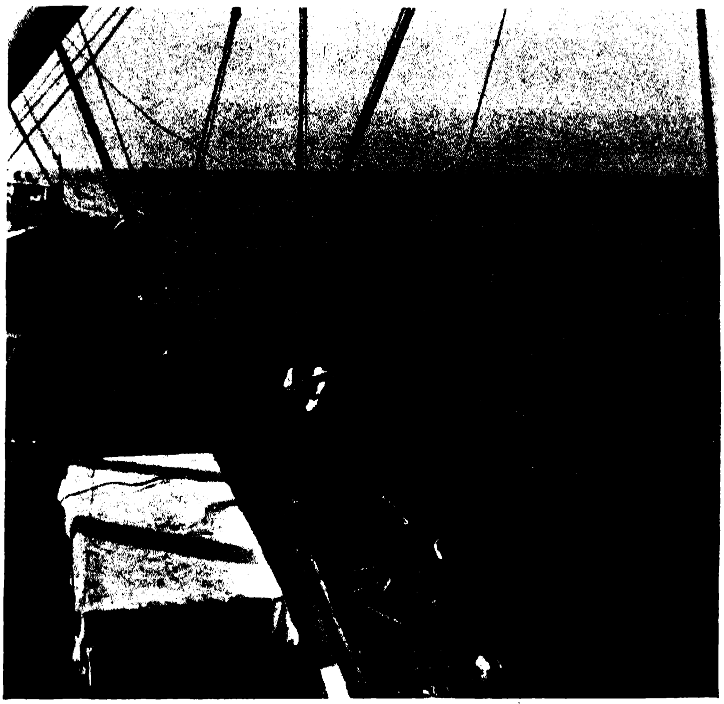


Fig. 1. The usual way of landing at West African ports. The "mammy-chair" transfers the traveler to a surfboat manned by a dozen paddlers.

the Hawaiian Islands. The trail of fruit flies and their parasites led to Sierra Leone, Nigeria, and the French Cameroons, with shorter stops in Liberia, the Gold Coast, the Belgian Congo, and Angola (Portuguese West Africa).* With J. M. McGough, the writer landed first at Freetown, Sierra Leone** on November 9, 1935.

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* A summary of the results of the expedition is given at the end of this article.

** Although Sierra Leone does not lie within the rain forest belt proper, there were good reasons for beginning the work there, and some of the most promising parasite material was obtained in that country.

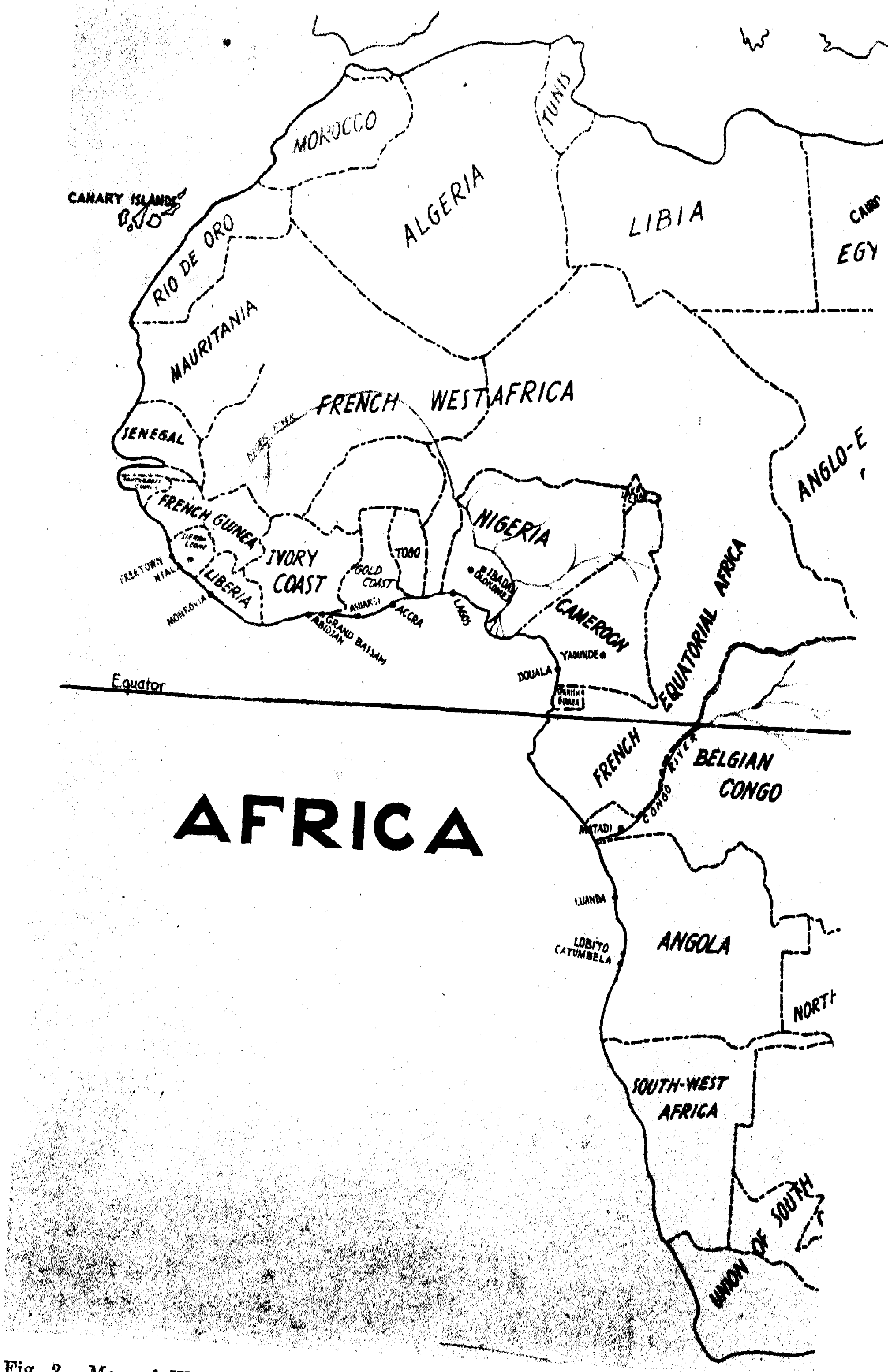

Fig. 2. Map of West Africa showing the regions visited between November 1935 and August 1936.

Climate and Rainfall

The climate of the "Coast" is notoriously trying. Heat is oppressive in the lowlands, where year-round temperatures average in the middle or upper eighties. Only in the Cameroons do mountains occur where relief from the enervating heat can be found. The coolest weather is during the few weeks of January when the steady harmatan blows, but this parching wind off the Sahara is a mixed blessing, looked forward to with dread.

The heaviest rains fall on shore lines which face the southwest: Sierra Leone, Liberia, and the Mount Cameroons region; these districts get from 160 to 200 inches each year. On the east-west part of the Coast, rain is heaviest at the sea and lessens as one goes inland; the reverse is true on the north-south portion below the mouth of the Congo. Between the Congo and the Cameroons there is little difference in rainfall between seacoast and interior. An exception to the general raininess of the coastal districts is the small arc of semi-dry country about Accra in the Gold Coast, where only some 40 inches fall annually.

The well-marked rainy season from April or May into November, is ushered in and out by electrical storms of great severity, accompanied by sudden, fierce gusts of wind.

There is both archeological and geological evidence that formerly Africa was more generally watered than it is today. The obvious sign of the continent's drying is seen on the northern borders of the West Coast colonies, where the Sahara sands each year make small steady advances southward.

Sierra Leone

The Freetown peninsula is the only high land on the coast between Morocco and the Cameroons; so the capital of Sierra Leone, with its backdrop of forested mountains, is a pleasant change after days of coasting past the unrelieved flatness of mangrove swamps and low shore. Freetown was the first colony on the continent to be founded by Africans repatriated from America. Sponsored by William Wilberforce, the English philanthropist, the first settlement was made in the late eighteenth century. Its early years were made difficult by the fierce attacks of local tribes and outbreaks of yellow fever, which, persisting long after the success of the infant colony was assured, took heavy toll of the small population. Today Freetown is a city of some 70,000—"Creoles" (the local name for the descendants of the early immigrants), indigenous natives, and a few hundred Europeans. The Freetown Creole is without firm roots in this part of Africa; neither his language nor his customs are those of the tribes which surround him. His ancestors came to America from the Niger delta, some 1500 miles to the eastward, so he is nearly as much a foreigner in his present location as any white man.

With few exceptions the Creoles are all Christians. Waves of warlike, semitic tribes (Foulahs, Temnis, Mandingoes, etc.), for the most part Mohammedan, have for centuries swept down on the West Coast from the northeast. A few indigenous agricultural tribes like the Mendés, have withstood this pressure, and remain in more or less their original areas. They are mostly pagan, but lately Christians and Moslems have made many converts among them.

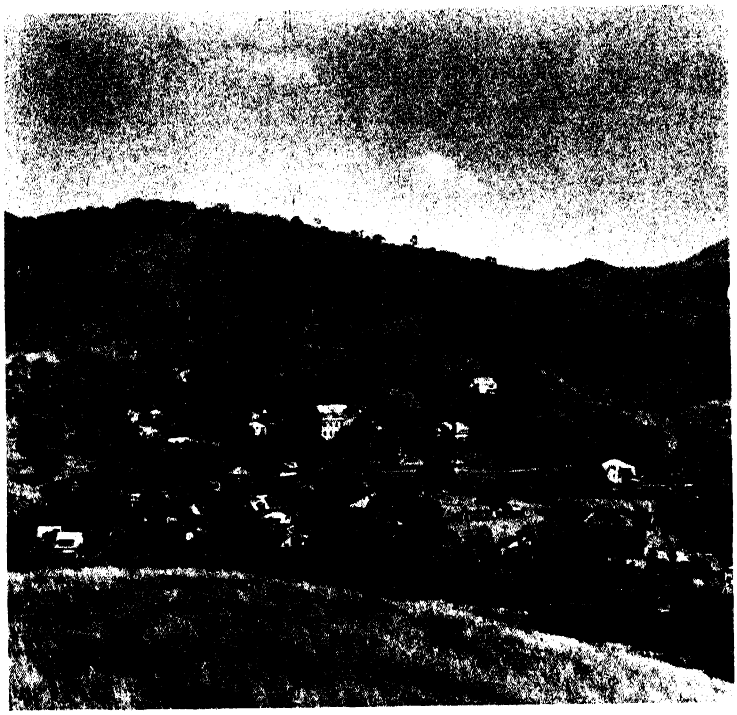

Fig. 3. Forested mountains back of Freetown, Sierra Leone; much of the forest shown here is a reserve furnishing the city's water supply.

The Freetown peninsula comprises the Colony, and the back country the Protectorate; together they have a population of well over a million. They are ruled according to the traditional British model of justice and security. Government is indirect, through native paramount chiefs elected for life; direct taxation is confined to a small hut tax. A school system is especially well developed in the Colony; a medical service maintains European physicians in the principal centers, and directs sanitary work. Government school and hospital facilities are augmented by those of the numerous missions. There is a Department of Agriculture, directed by Dr. F. J. Martin, with an experimental farm at Njala in the southern province where a small European staff is engaged in research and extension work. A forestry department is concerned, among other problems, with reforesting burned-over farmland no longer in cultivation.

Despite recent discoveries of platinum, gold, and diamonds, agriculture remains the mainstay of Sierra Leone, a country which has been self-supporting for many years. Oil and kernels of the oil palm *(Elaeis guineensis)*, and kola nuts are the important export crops. Kola nuts contain a powerful stimulant, and enormous quantities to be used by the natives are exported to the neighboring French colonies. Minor produce like ginger, peanuts, and piassava (the fiber of Raphia palms) is of considerable value. All of the above, except ginger and peanuts, are gathered from plants in natural conditions, not under cultivation.

No non-African can own land in Sierra Leone. The land, or "town-bush" of each native settlement belongs to that community, and its particular ownership, either by individuals or by families, is recognized by tribal custom. The typical native

farm, to which the owner and his family go out each day to work, is a mixed planting of corn, cassava, cotton, millet, peppers and miscellaneous food plants. The orchard bush is cleared and burned over before planting, and the ground is farmed for about a year. Moving to a new site yearly, the farmer returns to the first clearing, by now completely overgrown again, in about six years. Smoke columns from clearings being prepared for planting dot the countryside toward the end of the dry season.

Throughout West Africa the native's food habits are based largely upon introduced food plants. Crops introduced during the past five hundred years of contact with Europeans, have to a great extent replaced the native ones. The probably meagre diet of the aboriginal African (palm oil, yams, millet, game and a few native fruits) has been supplanted or added to by introduced foods like corn, rice, cassava, peanuts, bananas and other fruits. Corn has been the staple for so long in Portuguese West Africa that the Angolese believe it is a native plant. Improvement in diet, as well as the stopping of almost constant tribal warfare, may explain the great increase in native populations since the white man has dominated Africa.

The newcomer to Freetown senses a lack of something, without knowing what it is. Finally it dawns on him that it is the complete absence of horses and cattle. Tsetse fly-borne diseases make stock raising all but impossible in Sierra Leone, except in parts of the northern province. Goats and poultry are almost the only domesticated animals raised. The Njala experimental farm, by crossing the "native" fowl with the Rhode Island Red, has produced a strain well suited to local conditions. Fresh beef is imported from French Guinea; cow's milk is almost unknown except

Fig. 4. Oil palm. Growing wild in the heavy rain forest, this plant supplies the kernels and oil which are the backbone of West African commerce.

in cans. All butter is imported, but this necessity concerns only the European, for the native uses palm oil lavishly in all his cooking.

It is said that Sierra Leone's oil palm production might be greatly increased. The Department of Agriculture's large planting of palms near Freetown demonstrates the advantages of cultivation in a crop now entirely "wild." But whatever interest in planting palms this may kindle in the native, is cooled by the low price of oil and kernels. Production records at Njala show clearly that the local palm, which now produces the entire crop, might profitably be replaced by the more productive Nigerian variety.

The Agricultural Department has had notable success in fostering the rice industry. Formerly nearly all of this staple was imported, but now the country produces enough for its own needs, and with large areas of suitable land available, the present small exports of rice will doubtless increase. The cost of the local product is said to be less than that of imported rice from India.

Among the crops the department has tried to encourage by demonstration plantings, is citrus. Oranges and grapefruit of high quality are grown, but a serious problem has been the control of fruit-piercing moths. Adults of some fifty kinds of noctuid moths pierce the ripening fruit with their long tongues, and a dropping of the entire crop often results. From April to June the moths come to the groves from the "bush," where they have fed as larvae upon a wide range of native plants. The difficulty of discovering and poisoning the feeding grounds, and the migratory habits of some of the species, leave the adult as the only stage against which control can be directed. Ernest Hargreaves, the entomologist at Njala, has developed effective syrup baits for poisoning adult moths. It will interest Hawaiian fruit growers to know that one of the worst species in Sierra Leone (*Othreis fullonica* L.) occurs no farther away from these Islands than Fiji and Samoa.

Pineapples are often on sale in Sierra Leone markets, but are hardly a commercial crop. At Njala a few plants of Smooth Cayenne were seen. They appeared free from insects, but Mr. Hargreaves records two coccids on pineapple: one, the common pineapple mealybug, *Pseudococcus brevipes* (Ckll.), and the other a scale, *Diaspis boisduvalii* Sign. He has found a coccinellid beetle, *Hyperaspis senegalensis* Murr., to be predaceous on the mealybug.

Termites similar to the slow-working, drywood species of Hawaii occur in European-type buildings; their damage is seldom severe. The structures of ground-nesting termites are common in the southern part of the country, but the species apparently do not enter buildings, and no precautions are taken against them. Most native houses are so temporary in nature that they are usually replaced before termites damage them seriously. No effective enemies of termites are known in West Africa. Lizards and a calliphorid fly (*Ochromyia depressa* Walk.), which captures and feeds on stray individuals, prey upon white ants in general. Only when nests are accidentally broken, or flights are in progress, do they have access to them.

The Protectorate native lives much as his ancestors did, unaffected by the white man except for the benefits of improved health and personal security. Native houses are a single story high, usually of wood with walls of wattle and mud and floors of dirt. They are circular or rectangular in shape, according to tribal custom, and the roofs are thatched with grass or palm fronds, or covered with plaited palm-leaf "slates." The pagan native is highly superstitious. He believes that certain indi-

viduals can change themselves at will into wild animals; that the "boman" (actually the large, hammer-headed fruit bat) sucks the blood of children, and after their death turns into either stone or snake. The monotonous cries of these bats, common of an evening wherever ripening fruit occurs, brings out the entire village to drive away the animals by beating on tins, and by vigorous cursing of their parents and all their ancestors. Medicine men claim the power of invoking lightning by means of "thunder-axes" fashioned from meteorites. Secret societies, like the Human Leopard and Crocodile, formerly caused many savage and mysterious crimes, but the British have suppressed such activities. Much store is attached to "making medicine"; it is almost impossible to purchase a leopard skin from which teeth and claws have not already been removed for juju.

Fig. 5. Historic Ceiba or "cotton tree," Freetown; long a landmark for mariners, the slave market was held beneath its shade in former times.

The native takes pride in his person, and seems forever to be bathing. The use of the "chewing stick," a form of toothbrush, is universal; a soft stick (various kinds of wood are used) is chewed into a tuft of fiber at one end, and carried in the mouth during the early hours of the day's routine. Scars made by rubbing ashes into cuts in the skin are a common form of decoration, particularly elaborate among the women. Individuals are seen completely and symmetrically covered with a fine scar-design; the effect is artistic by any standard and to a pagan worth the pain of acquiring. Our Mendé steward boy had his middle upper teeth filed to sharp points, a sign, perhaps, that his father had been a member of a cannibal society.

The most characteristic Sierra Leone native products are the beautiful "country cloths," handwork from start to finish. Native cotton is cleaned, spun

and dyed by women, then woven by the men into distinctive and pleasing designs, usually blue or black on a white background. Basketware and articles of woven raffia and leather are of excellent workmanship. Such articles are colored with local vegetable dyes, a favorite being the red of camwood *(Baphia lobata)*.

The Kissi tribe, originally immigrants from the Sudan region, occupies a remote eastern section of the country and part of Liberia. Conventional money interests them little; their money consists of so-called "Kissi pennies," slender, foot-long rods of native wrought iron. Exchange varies from 12 to 14 for the English penny, but the Kissi prizes his curious currency for the intrinsic value of the iron itself.

Fig. 6. Mendé devil dancer; the costume is of raffia.

While at Njala, hearing the incessant throbbing of dance drums night after night, we went one evening to the nearby village of Mekundé and requested a dance. The chief had retired, but he emerged from his house with dignified courtesy and ordered out the entire village (of some 200 Mendé tribesmen) to perform for us. Surely many of the modern dances are pure African, for that night the unmistakable prototypes of Charleston and rumba were danced with a fervor not given to whites. So pleased was the chief (and all the villagers) with the shilling which we "dashed" him for the entertainment, that he offered to send some 30 miles away for special dancers if we would return the next day.

The following afternoon we were again seated on either side of the chief, before the "barri" or palaver-house. Then began a dance pantomime centering about a male and a female devil. Both wore raffia costumes which completely covered them, and grotesque wooden masks. The symbolism was clear to the

native spectators, but for us, in spite of a somewhat involved explanation by an interpreter, it was difficult to follow. It had something to do with the rites of the Porro and Bundu societies, the secret tribal organizations of the men and women respectively. Both devils seemed harmless characters, although the male demon, with sudden leaps and outcries, scared into frightened wails most of the small children who watched breathless from the sidelines. The man devil was made the butt and laughingstock of the afternoon by a ten-year old boy dancer who supplied comedy relief by impudent grimacing and teasing. Later we had a chance to observe that the impudence allowed this youngster by his dance role had no part in the everyday life of this well-mannered, African small boy. Throughout the long hot hours of the afternoon, the drumming (done with fingers or the palm of the hand) continued without a break, even during the intervals when the dancers rested.

Fig. 7. Mendé village, southern province, Sierra Leone, showing the native architecture.

Liberia

The Republic of Liberia, the only remaining independent country in Africa, is of special interest to Americans. American philanthropic societies bought land along the Liberian coast from native tribes for settlement by negroes from the United States. The first colony was founded in 1821; others soon followed, and in all, four or five separate settlements were made. Because of difficulties arising from their vague international position, the colonists finally united to form a republic in 1847. Great Britain recognized Liberia the following year, but the United States did not take similar action until 1862. There has been almost

no immigration into Liberia since the American Civil War. The relatively few descendants of the immigrants from America (locally called "Liberians" to distinguish them from the indigenous natives), some 20,000 in all, are the dominant class in the country. The natives, totalling perhaps a million, contribute an increasing number to the ruling class as their opportunities increase, but in general, government and economic control are in the hands of the American-Liberians.

The language of the educated Liberian is American, and his cultural background American rather than European. The influence of the Old South is plainly seen in the architecture of Monrovia, and to some extent the social and economic ideas of the same section have also survived. The original ideal of a country of small independent farmers seems largely to have been lost sight of, and among the well to do there has arisen a leisured planter class.

Fig. 8. Typical better-class residence, Monrovia, Liberia.

Liberia is about the size of the state of Ohio, and lies almost entirely within the rain forest belt. There is a relatively small proportion of grass land to forest. Numerous short rivers lead into the interior, and these afford the only communication with the back country except for trails. Roads are being extended, but improvements of this sort, as well as the bettering of educational facilities and health conditions are hampered by lack of money.

The only large concession is that of a large American rubber company, which has obtained the right to plant up to a million acres. Its several plantations are devoted to Hevea rubber, and production is mounting annually; its largest area, with perhaps 100,000 acres already planted, is near Monrovia. The company depends almost entirely on its own rubber, but encourages production by native

Fig. 9. Market stall, Waterside, Monrovia; the stock in trade here consists of pineapples, bananas, avocados, and peanuts.

Fig. 10. An umbrella shades this vendor's stock of merchandise in the Monrovia market.

growers also. Despite a potentially large labor supply, one of the chief difficulties is maintaining an adequate force of natives.

Liberia suffered acutely from the disruption of commerce attending the World War, and only lately has recovery begun. The country's reliance in the past has been upon exports of agricultural produce (palm oil, palm kernels, and coffee principally), but with the wartime experience in mind, it is probable, according to students of the country, that in the future Liberia will tend to become more self-sustaining and to develop more of its native resources.

Among the indigenous tribes of Liberia the Kru race is exceptional. Originally farming tribes like the rest of the indigenous natives, the Krus have gained a reputation as seafarers, and man all the European vessels running along the West African coast. They still wear a tattoo mark on the forehead, a relic from less secure times when it exempted them from capture and forced labor.

GOLD COAST

For over 200 years the Gold Coast was the scene of the bitterest commercial rivalries between Portuguese, Swedes, Brandenburgers, Dutch, and English. Traffic in natives attracted merchant companies more strongly than even the gold deposits. For the protection of their traders the companies erected great castles along the coast, some of them as early as the fifteenth century. A few, like Elmina and Cape Coast castles, are still in excellent repair, and in use today for government purposes; Christiansborg castle, near Accra, is the residence of the governor. These stately structures are everything demanded by romantic notions of what a

Fig. 11. Termite nest, Njala, Sierra Leone; the species is probably *Cubitermes silvestrii* Sjöst.

castle should be—moats, drawbridges, enormously thick walls, battlements, barracoons, and dungeons.

Private ownership of land does not exist in the Gold Coast; land is community property and its use is allocated by the chiefs according to tribal custom. The system has been slightly modified to permit the longer tenure necessary to crops like cocoa, but the land is still communal. As in all the British West African colonies no land is available to anyone not of African blood. Gold Coast natives seldom have to hire out as laborers, so the companies engaged in mining import labor from the nearby French colonies.

Cocoa, palm oil (and kernels), and kola nuts are the leading agricultural products of the colony. Cocoa not only overshadows all other farm products, but the mining output as well. Starting from almost nothing, cocoa production has increased within the past 25 years until it is now nearly half of the entire world crop of some 600,000 tons. All is produced by small peasant communities, and comes from the southern part of the colony where the annual rainfall is from 60 to 70 inches. Formerly Gold Coast cocoa was of low quality, but since the development of the Department of Agriculture's inspection service, rejections of export cocoa have dropped to about 12 per cent. Among the cooperative societies sponsored by the department, the quality is even higher, rejections being but 2 per cent. Rejections are usually for fungus and insect damage (the latter mostly due to *Araecerus fasciculatus* De G. and *Ephestia sp.*), for imperfections of color, improper fermentation, etc.

The Department of Agriculture, directed by G. G. Auchinleck, is staffed by 45 Europeans and some 100 natives. Besides inspecting export farm products, it organizes and gives financial aid to small cooperative groups (of which about 3,000 have been formed in the cocoa industry), maintains statistical records for all crops, and carries on research at its main station at Aburi, near Accra, and at its Assuansi fruit farm in the western province. At the latter station the normal 8-year cycle of general agricultural practice has been cut in half by using *Centrosema pubescens* as a covercrop. By pasturing native sheep on another legume planted in citrus orchards, the station maintains fertility at a high point and incidentally produces an extremely cheap mutton. Native farmers approached on the subject of covercrops, demand first that the covercrop be edible; such a crop, a native species of Mucuma, has been found at Assuansi. None of the various kinds of pigeon pea tried has done well in the Gold Coast. Near Assuansi is the plant of a well-known producer of lime juice, a firm now withdrawing from the West Indies to concentrate in West Africa; all its fruit is purchased from natives.

The Gold Coast is one of the most obviously progressive of the West Coast colonies. A recent governor, the late Sir Gordon Guggisberg, a Canadian by birth, left an impressive monument of public works, at a cost of some 9 million pounds. Besides extending the railroad system and the network of paved roads, he built a breakwater and modern harbor at Takoradi, and at Accra, the Korlebu native hospital which is the last word in hospital planning. He built also the magnificent Achemota College to which come natives of both sexes from all parts of West Africa to study from kindergarten on, through such specialized courses as law, medicine and engineering.

Nigeria

More than three times larger than Great Britain itself, Nigeria, with its 20 millions, is the most populous of all the British colonies in Africa. It is a land of plains lying almost entirely within the basin of the Niger river. There is a wide coastal belt of swamp and mangrove country, then a heavily forested belt, above which lies the greater part of the country, an undulating plateau of grass and bush.

Its principal agricultural products have long been palm oil and kernels, and livestock. Stock is raised principally for milk and hides, beef production being unimportant; the industry, because of tsetse fly in most of the country, is confined to the northern part of the colony. Farmers rarely own livestock; most of it is raised by pastoral tribes not engaged in any other sort of agriculture. Since the war, cocoa, peanuts ("groundnuts"), and cotton have been developed into major importance. Further increase in oil palm production is said to depend upon solving labor problems involved in the gathering of the wild crop over enormous tracts of forest.

The Department of Agriculture has its main experimental farm at Moor Plantation, near Ibadan, a city of about a quarter of a million, said to be the largest native town in Africa. Several other stations are located at various points about the country. To maintain soil fertility the department is trying to increase the use of cattle on farms, and to encourage crop rotation. At the Ibadan farm an unusual use was being made of corn; it was grown as an indicator crop in soil fertility tests. Most native farms are extremely small, and cultivation consists of a superficial hoeing; there is much more land available than can at present be used.

Migratory locusts are the worst single pest of general agriculture. Their principal breeding grounds are in the Lake Tchad region, and the Nigerian Department of Agriculture has, for several years, conducted a project of investigation and control in cooperation with the French authorities within whose territories the "hoppers" hatch.

There are over 50,000 square miles of rain forest and fringing forest in southern Nigeria, all administered by the Nigerian forests department. Operations are supervised by European forest officers who designate which trees shall be cut. Important timber trees are "African mahogany" *(Khaya ivorensis)* and "West African (or Sapele) mahogany" *(Entandophragma cylindricum)* which is heavier and harder than the other African "mahoganies." Large amounts of *Lophira alata* are cut for railroad ties. In the forest reserve at Olokemeji in southern Nigeria are large plantings of oriental teak, some of them over 25 years old; they have made good growth, but no commercial use has been made of them.

Colonies of a termite with nasute soldiers, nesting in low mounds, were common in the open country about Olokemeji. The upper galleries in the structures built by this species invariably contained quantities of grass cut into nearly uniform lengths. It was in the forests that we found columns of the driver ant *(Dorylus spp.)* most common. The compact mass of the main column streams blindly along, fringed by a less conspicuous screen of scouts which quickly rout the observer, along with smaller animal life, out of his complacency. The

Fig. 12. Native structures used for storing corn, near Ibadan, southern Nigeria.

Fig. 13. Native market, Olokemeji, southern Nigeria. The large bundles are raffia used as pads under head loads.

large, cylindrical, winged males of the driver ant are a common feature of West Africa, flying clumsily about lighted rooms at night; they are known as "sausage flies."

One day while traversing a path which emerged from the forest near Ibadan, we observed a very large wasp, *Hemipepsis heros* Guer., flush out of the grass a specimen of the mouse-large cricket (*Brachytrypes membranaceus Drury*) which is a serious garden pest as far westward as Sierra Leone. After grappling with the cricket for some moments, the wasp paralyzed it, and was in the act of dragging it off, presumably to an underground burrow, when it was captured. The cricket was kept several days, but died without regaining activity. The psammocharid group to which Hemipepsis belongs generally stocks its nests with paralyzed spiders; the above observation (the wasp was compared with named material in the entomological collection at Moor Plantation) indicates that there are exceptions to the general rule.

In eastern Nigeria, in that part of the former German Cameroons now administered by the British as a mandate from the League of Nations, occurs the only exception to the British West African policy of land for the natives only. Large land concessions were made to Europeans before the war, and have remained unaltered since. The planters are mostly Germans engaged in banana culture; production has increased so greatly of late years that there is now a line of fast steamers taking the fruit direct to Europe.

French Cameroons

Even more picturesque than Freetown after the monotony of flat coastline, is, having passed a hundred miles of muddy-mouthed Niger delta, to steam between the 13,000-foot peak of Cameroons Mountain and the Spanish island of Fernando Po. East of and behind the majestic mountain, the ship enters the muddy flats of the Wuri river, twenty miles up which lies Douala, the chief port of the French mandate. The town lies on a low bluff in the midst of swamps and high forest which in many places comes to the water's edge; it is important commercially, and the starting point of the railroad. Some 200 miles inland one branch of the line, after winding up into the mountains, ends at Yaoundé, the capital, where it connects with an enormous motor road system. In one direction a road runs along the back of the British colonies westward to Dakar in Senegal; in another to the French outposts in the Sahara; in a third, south into equatorial Africa; and finally in another, through the Belgian Congo into Uganda.

The familiar oil palm, in the Cameroons as elsewhere, is the backbone of commerce. For the most part a wild forest crop, there are plantings of it in the Mount Cameroons region. Next in importance come cocoa, timber, and rubber. Most of the rubber is obtained from Landolphia and *Kickxia elastica* growing wild in the forest, but there are a few pre-war plantings of Kickxia as well as of the Brazilian Hevea.

The Cameroons is largely peopled by Bantu stock, a race occupying the entire breadth of Africa from there to the Cape of Good Hope. In this mandate they build long, rectangular houses with walls of bamboo or palm splints lashed grid-like and plastered over with mud; the roofs are covered with units of plaited palm

Fig. 14. Raphia palm, Lumley Beach, Freetown. A versatile tree from which are obtained piassava fiber and palm wine.

Fig. 15. Young leopard, Sierra Leone; the West African variety is much darker than others of the same species occurring elsewhere on that continent or in India. This leopard is now in a zoo in the eastern United States.

leaves. Ventilation is through the single door and the very small window placed just under the roof-peak at either end of the house. Villages are commonly strung along the road, one house deep, with clearings cut out of the high forest behind the houses. A town thus forms a single long street, sometimes miles long.

Well-made crossbows are used for hunting small game; the strong tension of the string is released by a simple trigger device. The arrows, which are unfeathered, are highly prized, and a hunter will search for hours to retrieve them. This weapon is said to be indigenous to this part of Africa, and not copied from the medieval European crossbow which natives might supposedly have seen in the hands of early voyagers.

To find clear traces of Uncle Remus in the Cameroons, was one of the most pleasant of many surprises. We heard several Ewonde native stories which differ from those of Joel Chandler Harris only in local substitutions for the familiar Br'er Rabbit and Br'er Wolf. Similar legends are widespread on the West Coast, and it seems not improbable that the Georgia plantation stories are direct importations from Africa, modified only to fit a new land.

A higher proportion of Christian natives is said to be present in the Cameroons because mission work has been carried on longer there than elsewhere in West Africa. The missions have numerous schools and hospitals throughout the mandate, those of the American mission at Ebolowa, founded in 1885, being among the longest established.

Yaoundé, at an elevation of 800 meters in hilly country, lies between rain forest and grass savannah. In spite of some blackwater fever, it is healthier than the hot lowlands, and is a favorite rest resort for officials from the coast towns. Douala and Yaoundé are attractive towns, planted to many kinds of native and introduced ornamental plants. It was surprising to observe the wide use of panax and hibiscus, the latter said to have been brought from Hawaii during the German regime. Throughout the country, and in the colonies to the west as well, lemon grass *(Andropogon schoenanthus)* is planted to hold soil on road shoulders and railroad embankments.

Wild life finds a paradise in the Cameroons. Even from the train it is not unusual to see troops of mango monkeys, the gray African parrot in solitary flight, its wingtips a vivid red, or the grotesque hornbill, sentinel-like on a commanding treetop. Although the highlands are the home of gorillas and elephants, we personally saw neither. At one plantation the owner complained that elephants had run through his garden the night before; we saw fences and small shacks demolished or pushed over, the plantings completely ruined.

A yellowish variety of the oriental ant, *Oecophylla smaragdina* (Fabr.) which occurs throughout West Africa, was conspicuous about Douala and Yaoundé. This ant nests within clusters of tightly-webbed leaves; the foliage is fastened together by silk secreted by the larvae, which are employed like shuttles by the workers to bind the leaves together. This insect is very common in citrus trees, and being large and vicious, defends its colonies with effective vigor.

Another ant, smaller and darker than Oecophylla, was seen in large groups on bare, unwebbed foliage. When alarmed it bent its abdomen upward, and with feet firmly braced, jerked rapidly forward and back in perfect synchrony, the

Fig. 16. Nest of unidentified termite, southern Nigeria.

Fig. 17. The same nest opened, showing stores of cut grass in the upper galleries.

many ants moving as one; a plainly audible sound almost like a hissing accompanied these maneuvers.

The Cameroons medical service is highly developed, with particular attention paid to sleeping sickness. One of the worst centers for this disease is in the Ayos district, east of Yaoundé. To Ayos every medical officer just out from France goes to acquaint himself with the newest developments in the treatment of the disease. To leave the Mandate, by steamer at least, the traveller must have an official statement that he is free from sleeping sickness.

White French settlers are fairly numerous in the Cameroons. The result is an atmosphere quite different from that in the neighboring British colonies where the white population is largely official and essentially temporary. The white man in British West Africa leads a divided life; his children, and part of the time, his wife, remain at home in Europe. The Frenchman in the Cameroons, on the other hand, whether because of better climate or the opportunity to own land, establishes his home and family on his mountain plantation or timber concession, and seems to look forward with less urgency than his colonial neighbor to the distant time when he leaves Africa for home and a comfortable retirement.

"The White Man's Grave"

No discussion of West Africa is complete without some comment on health conditions. The medical and sanitary services of the West African colonies are well organized and of high caliber. Modern medical science has erased Sierra Leone's old stigma of the "white man's grave"; but in spite of improvement, West Africa is not a healthy place for the Caucasian. It is particularly trying on children, and in the British colonies none of the white officials are permitted to have their children with them.

The high humidity and enervating heat tax the European's strength and often pave the way for the onset of diseases peculiar to the country. Malaria, dysentery, and parasitic worms are perhaps the commonest maladies. Yellow fever, less frequent now than formerly, still threatens the entire Coast; sleeping sickness, usually a disease of natives, is confined to comparatively small and restricted areas.

The control of malaria, because of the magnitude of mosquito control over enormous areas of wild country, depends almost entirely upon quinine prophylaxis; most Europeans take this drug daily throughout their entire stay. The soft-leather, knee length mosquito boot, almost universally used by the whites in the British colonies, effectively wards off attack. Prevention of mosquito breeding is restricted to European communities and their immediate surroundings. The difficulties of such work on a larger scale are aggravated by the discovery of a malarial vector, the larva of which gets its air through the stems of aquatic plants, a habit making treatments with oil or arsenic ineffective. The newcomer to Freetown is apt to minimize the importance of malaria because of the comparative scarcity of mosquitoes. However, the Sir Alfred E. Jones Laboratory of the Liverpool School of Tropical Medicine, has found that the malaria-infectivity of mosquitoes about Freetown is very high, about 35 per cent. Most of the West Coast malaria is of the malignant tertian type, and the most prevalent vector,

Fig. 18. Native market, Freetown.

Fig. 19. Native market, Freetown; the woman on the left is selecting Kola nuts from the tray.

Anopheles gambiae Giles. Associated with malaria in some imperfectly understood way, is blackwater fever, said to be particularly frequent in the Cameroons.

As a result of its work in Nigeria, the Rockefeller Institute has developed a serum treatment believed to afford certain protection against yellow fever. It has been used only a few years, but it is said that none of their laboratory workers on yellow fever who have received the treatment have contracted the disease, while previously a few became accidentally infected every year. Immunity is presumably lifelong. Treatment is obtainable at present only at the Institute in New York and at the Wellcome Bureau of Scientific Research in London. The Imperial Airways, recently opening a line from Khartoum to Lagos, gave the serum to all of its crews on the West African run. If, as seems probable, the resident of those regions over which yellow fever now hangs as a permanent dread can eliminate so simply the possibility of this disease, a forward step of tremendous importance has been made.

Fruit Fly Investigations*

Nine months on the "Coast" resulted in getting alive to Honolulu 750 braconid wasp parasites of the larval stages of several kinds of fruit flies; they represent about a dozen parasites new to Hawaii.** These parasites are not necessarily specific upon a single kind of fruit fly, and at least some of them from other species can adapt themselves to the Mediterranean fruit fly (*Ceratitis capitata* Wied.). Two (*Opius perproximus* Silvestri and *Biosteres caudatus* Szepl.) have been released in numbers sufficient to give them a good chance of establishment here.

Our stay in Sierra Leone and in the Cameroons coincided with fruiting seasons of many wild fruits; in the other countries visited we were either too late or too early for the best results. When ripe fruit was available, getting parasites was fairly simple; the problem, even with relay stations in the United States where they were fed en route, was to keep them alive across the 9,000 miles between Africa and Honolulu. Personally conducted shipments were the most successful; a laboratory was improvised aboard ship which usually had a chill room available, and there the wasps were reared and cared for until their arrival in the eastern United States.

The Mediterranean fruit fly appears to be rare in the countries covered by this report. Only two specimens were captured, both in southern Nigeria, and nowhere did we breed it from fruit. It had previously been recorded from Togo, Nigeria and the Belgian Congo, but the only breeding record for the species in West

* The flies named in the following have been identified by C. T. Greene of the United States National Museum. Parasites named to species were identified by C. F. W. Muesebeck; the rest have not yet been authentically identified. The search for fruit fly parasites in West Africa and elsewhere was under the direction of C. P. Clausen, in charge of foreign parasite introduction for the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture.

** Previous work by Dr. Filippo Silvestri, D. T. Fullaway and J. C. Bridwell, in 1912-1914, resulted in the establishment in Hawaii of the following African parasites of fruit flies:

Opius humilis Silvestri (larval parasite).
Opius (*Diachasma*) *fullawayi* (Silvestri) (larval parasite).
Tetrastichus giffardianus Silvestri (larval parasite).
Galesus silvestrii Kieffer (pupal parasite).

Africa is by G. S. Cotterell from citrus in the Gold Coast. The native host fruit of this fly therefore remains to be discovered, unless it is coffee, from which it has been bred in East Africa.* We doubt if its real home is in the West African lowlands; it is more probably in the mountainous forests of equatorial or East Africa.

Fruit flies are of little economic importance in West Africa because they are usually in wild fruits of no value; an exception is the dacine (melon fly) group which is a severe pest of cucumbers and other cucurbits. Support was found for the belief that the ceratitine group (*C. capitata* a prominent exception) is indigenous to this part of Agrica. Flies of this subfamily, as well as their parasites, were common only in native fruits; in the rare cases that they infested non-native fruits, their parasites apparently had not followed them into the new plant hosts. Dacine flies, whether in introduced or (more rarely) in native fruits, were seldom parasitized.

There follows a discussion of the principal sources of fruit flies found in the various countries.

Sierra Leone

(Nov. 9, 1935-April 4, 1936; July 23-28, 1936)

Nearly 100 kinds of native and introduced fruits,** totaling many thousands, were examined for fruit flies at Freetown and Njala without result. Infestation was confined to a comparatively small number of host species, most of them indigenous African plants.

Momordica charantia L. Family Cucurbitaceae. Fruits collected at Freetown in July yielded specimens of *Dacus brevistylus* Bezzi, *Dacus ciliatus* Loew and *Dacus* near *punctatifrons* Karsch; no parasites were obtained. The plant is not African, but occurs widely throughout the tropics.

Cucumbers. Obtainable throughout the year, this vegetable is very heavily infested by *Dacus pectoralis* Walk. Large numbers of flies were obtained, but parasitization was almost nil. From 400 puparia obtained in December, 3 specimens of Opius were bred, but 100 per cent emergence of flies was usual in many large lots of puparia.

Passiflora foetida L. Another widely distributed plant not native to Africa. Fruits ripen throughout the year; they seldom drop, even when infested. A single species of fly, *Dacus punctatifrons* Karsch, was reared from this material. At Njala there was one case of parasitization (by *Tetrastichus giffardianus* [Silv.], a parasite previously established in Hawaii) out of 1356 puparia, while at Freetown no parasites whatever were bred from similar material.

Sarcocephalus esculentus Afzel ("Sierra Leone peach"). Family Rubiaceae. Indigenous from Senegal to Angola, eastern Sudan and Uganda; a tall tree under forest conditions, but in orchard bush a scandent shrub attaining 20 feet. The large, reddish fruit has two main ripening seasons in Sierra Leone: November into

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* By the late A. H. Ritchie.

** Thanks are due to F. C. Deighton, mycologist at Njala, for the identification of most of our Sierra Leone plant material.

February, and May into August; a few ripe fruits can usually be found at any time of year.

The only trypetid bred from this fruit was *Ceratitis giffardi* Bezzi (*C. cosyra* Walker).* Egg laying takes place even while the fruit is green and very hard; infestation is fairly heavy. Fruits at Njala in November showed 42.8 per cent parasitization by three species:

Biosteres caudatus—21.7 per cent (72 males, 133 females)
Opius perproximus—16.9 per cent.
Tetrastichus (prob.) *giffardianus*—4.2 per cent.

Chasalia afzelii K. Schm. Family Rubiaceae. A shrub, doubtfully indigenous, which we found only in Sierra Leone; the berries ripen in November. From 40 fruits at Njala were obtained 28 puparia of *Ceratitis (Trirhithrum) coffeae* Bezzi and four females of an all-black braconid.

Conopharyngia longiflora Stapf. Family Apocynaceae. Indigenous from Senegal to the Ivory Coast. Ripe fruits were most common from November to February, but a few can usually be found the year round. *Ceratitis punctata* (Wied.) was the only fly bred from this fruit, and infestation was usually light. *Opius perproximus* and *Hedylus giffardi* Silv. were obtained from puparia of flies in this fruit.

Adenia lobata Engl. Family Passifloraceae. An indigenous woody climber ranging from Senegal to Spanish Guinea and Angola. Fruits ripened at Njala in November, and at Hill Station, near Freetown, in July. An undetermined species of Tridacus was bred, but the mortality of larvae before pupation was invariably high; no parasites were obtained. This is the one instance in Sierra Leone of a dacine fly breeding in a native fruit.

Coffea liberica Bull ex Hiern. Family Rubiaceae. Cultivated from Senegal to Angola, and said to be indigenous to Liberia. Berries collected near Freetown in December were lightly infested by *Ceratitis (Trirhithrum) coffeae*, and a single adult Opius was obtained from the same material. Berries were immature in July.

Chrysophyllum pruniforme Engl. Family Sapotaceae. A tall, indigenous, forest tree from Sierra Leone to Angola, and from Kenya to Natal. In Sierra Leone there is a single crop yearly (December to March) of round fruits somewhat over an inch in diameter. Infestation by *Ceratitis punctata* was extremely heavy, with an incomplete record showing an average of nearly 18 maggots per fruit.

Of the 4007 puparia collected in December, 17.9 per cent had been parasitized:
Opius perproximus—699 (288 males, 471 females).
Hedylus giffardi—20.
Tetrastichus—2.

From 19,751 puparia obtained in January and February, the following emerged:
Opius perproximus—12.6 per cent (855 males, 1635 females).
Hedylus giffardi—1.1 per cent (50 males, 172 females).

*** A few specimens of *Ceratitis* (*Trirhithrum*) *coffeae* Bezzi were bred from this fruit, but in insignificant numbers.**

Opius greatly outnumbered Hedylus in these two cases, the totals of both records being, Opius 3189, Hedylus 244.

Anisophyllea laurina R.Dr. Family Rhizophoraceae. Indigenous to French Guinea, Sierra Leone and Nigeria. Confined to the coastal region (up to 800 feet or more) in Sierra Leone, it has a single annual crop, ripening abundantly in March. Infestation by *Ceratitis anonae* Graham was fairly heavy, but parasitization (by a single unidentified Opius) was disappointingly low.

Nigeria

(April 17-May 17, 1936)

At Moor Plantation near Ibadan numerous insects were attracted for a few days to the nectaries of *Gliricidia maculata,* a legume planted as a windbreak. Among them were these fruit flies:

Dacus vertebratus Bezzi
Dacus ciliatus Lw.
Ceratitis sp. near *cosyra* Walk.
Ceratitis capitata Wied.
Ceratitis anonae Graham.

The only infested fruits procurable at Moor Plantation were a very few *Momordica* probably *charantia* L. From these were bred *Dacus brevistylus* and the following parasites in order of their numbers:

Opius sp. (reddish body, black head)
Braconid with ovipositor about as long as in Hedylus
Biosteres (probably) *caudatus*

In the forest reserve at Olokemeji our second specimen of *Ceratitis capitata* was taken by sweeping the foliage of a forest path; *Dacus rufus* Bezzi (?) and *Carpophthoromyia n. sp.* were obtained similarly.

The following ripe fruits were available at Olokemeji:

Napoleona probably *vogelii* Hook. and Planch. Family Lecythidaceae. A native shrub or tree up to 50 feet, ranging probably from Sierra Leone to Nigeria; the main crop ripens, we were told, in July. From it were bred *Ceratitis punctata* and *Conradtina acroleuca* Wied., as well as the same parasites apparently as were obtained from Momordica at Ibadan:

Hedylus-like braconid
Opius sp.

Parasitization in this fruit totaled less than 5 per cent.

Landolphia sp. Family Apocynaceae. Two fruits were obtained, from which was bred *Ceratitis capitata,* but no parasites.

Adenia sp. (?) A passifloraceous vine unknown to the forest officers, but much resembling *A. lobata* of Sierra Leone. *Tridacus pectoralis* (Walk.) was bred in considerable numbers, but no parasites.

Conopharyngia penduliflora Stapf. Numerous *Ceratitis cosyra* Walk. were bred from this apocynaceous fruit, but there were no parasites.

French Cameroons

(May 20-June 20, 1936)

If further study of African fruit fly parasites is ever considered, Yaoundé would be an excellent site for a laboratory. Located between rain forest and tree savannah at an elevation of some 2500 feet above the sea, the good roads in all directions, the variety of the vegetation, and the comparative coolness of the region, form a combination unequaled in the lowlands of West Africa. A wider variety of parasites seemed present than in any other place visited. This was also true of the fruit flies; during a single day in the forest, the following were swept from foliage:

Tridacus bivittatus Bigot
Carpophthoromyia n. sp.
Bistrospinaria fortis Speiser
Ceratitis sp., near *cosyra* Walk.
Ceratitis punctata Wied.
Ceratitis anonae Graham

In late May forest fruits were coming into season about Yaoundé, and although many were uninfested, the following were found with fruit flies:

Myrianthus arboreus P. Beauv. Family Moraceae; Yaoundé name "ngakom," a large tree usually in damp places in the forest, ranging from Sierra Leone to Uganda, and south to Angola. The large composite fruits, yellow when ripe, attain a diameter of about five inches. *Ceratitis anonae* was the only fly reared from large quantities of fruit, but infestation was fairly heavy. The following were bred from Myrianthus fruits:

Tetrastichus (probably) *giffardianus*
Biosteres (probably) *caudatus*
Hedylus-like braconid with long ovipositor and black head; general color reddish.
Two specimens of a hymenopteron, probably hyperparasitic.

A group of not less than 1000 puparia of *C. anonae* from Myrianthus showed a total parasitization of 50 per cent; 17.5 per cent was by Tetrastichus.

Conopharyngia spp. Infestation was fairly light; three flies were obtained: *Ceratitis punctata, C. anonae* and *Carpophthoromyia n.sp.* The following parasites were present:

Tetrastichus (probably) *giffardianus*
Biosteres (probably) *caudatus*
Hedylus-like braconid; reddish with both head and abdomen black.

Cola spp. A few kola pods were found, heavily infested by *Ceratitis anonae.* From them were obtained Biosteres and the same Hedylus-like wasp bred from Conopharyngia.

Unknown forest fruit about the size, shape and color of a large olive; Yaoundé name "mbazo'o". Few fruits were infested, but those fairly heavily by *Tridacus*

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humeralis Bezzi. From them were bred Biosteres and a single female of a reddish Opius.

Avocado. A few heavily infested fruits of a thin-skinned variety obtained from a native garden near Yaoundé, yielded *Ceratitis anonae,* but no parasites.

Mr. McGough, remaining in Yaoundé until August, obtained there the following additional fruits containing flies and, in some cases, parasites:

Gutt iferae. Working with two species of fruit, from both of which he bred Ceratitis, Mr. McGough obtained from the larger, two braconid species, one black, the other red.

Gourd. Dacus sp. and an Opius (?) and a Biosteres (?) were bred.

Squash. A species of Dacus, but no parasites.

Eggplant. A Dacus and a small Hedylus-like parasite.

"Abam," unknown fruit. A Ceratitis was bred from this, and two parasites: Biosteres and Hedylus.

At the same season that ripe fruits were plentifully available in the Yaoundé district, a thorough search of the lowland forests near Douala was unproductive. The only ripe fruit abundant was of a dooryard tree, everywhere present but uninfested; known to English-speaking residents as "bush butter" it definitely was not Butyrospermum. In the rain forest was found a single infested fruit from a small unidentified tree; the fly maggots in this died before pupating.

Despite our inability to discover fly-infested host fruits in the lowlands, we found *Carpophthoromyia n. sp.* to be very numerous along roads and in forest clearings about Douala. This fly is identical with the single specimen taken at Olokemeji, Nigeria, and with that bred from Conopharyngia at Yaoundé. Another species taken in the forest near Douala was *Ceratitis cosyra.*

Belgian Congo

(July 2-6, 1936)

The lower Congo valley, at least for the 80 miles from the sea to Matadi, is a semi-arid country unfavorable for finding fly-infested fruits. During a stopover at Matadi the only infested fruits to be found were a handful of Momordica taken in a native garden some 20 miles south of the river. From these was bred a new species of Dacus near *chrysomphalus* Bezzi, but no parasites. Although the Belgian Congo has not been studied intensively for fruit flies, it is an extremely rich country entomologically, and investigation of its forest fruits for fly parasites should be profitable.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 16, 1936, TO DECEMBER 10, 1936.

Date		Per Pound	Per Ton	Remarks
Sept.	16, 1936	3.61¢	$72.20	Cubas.
"	17	3.555	71.10	Puerto Ricos, 3.55; Cubas, 3.56.
"	18	3.505	70.10	Puerto Ricos, 3.50; Cubas, 3.51.
"	21	3.50	70.00	Various raws ex store.
"	22	3.46	69.20	Various, 3.45; Cubas, 3.46; Philippines, 3.47.
"	23	3.405	68.10	Cubas.
Oct.	1	3.40	68.00	Philippines.
"	2	3.35	67.00	Puerto Ricos, Philippines.
"	13	3.375	67.50	Philippines, 3.35, 3.40.
"	14	3.36	67.20	Cubas, 3.35; Philippines, 3.36, 3.37.
"	15	3.35	67.00	Cubas.
"	19	3.40	68.00	Philippines.
"	21	3.39	67.80	Puerto Ricos.
"	29	3.355	67.10	Puerto Ricos, 3.35; Philippines, 3.35, 3.36.
Nov.	2	3.40	68.00	Philippines.
"	4	3.55	71.00	Philippines, 3.50, 3.55, 3.60.
"	5	3.65	73.00	Puerto Ricos.
"	6	3.69	73.80	Cubas, 3.68; Philippines, 3.70.
"	16	3.65	73.00	Cubas, Philippines.
"	18	3.70	74.00	Philippines.
Dec.	1	3.85	77.00	Cubas.
"	2	3.81	76.20	Cubas.
"	10	3.78	75.60	Cubas.

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Despite our inability to discover fly-infested host fruits in the lowlands, we found *Carpophthoromyia n. sp.* to be very numerous along roads and in forest clearings about Douala. This fly is identical with the single specimen taken at Olokemeji, Nigeria, and with that bred from Conopharyngia at Yaoundé. Another species taken in the forest near Douala was *Ceratitis cosyra.*

Belgian Congo

(July 2-6, 1936)

The lower Congo valley, at least for the 80 miles from the sea to Matadi, is a semi-arid country unfavorable for finding fly-infested fruits. During a stopover at Matadi the only infested fruits to be found were a handful of Momordica taken in a native garden some 20 miles south of the river. From these was bred a new species of Dacus near *chrysomphalus* Bezzi, but no parasites. Although the Belgian Congo has not been studied intensively for fruit flies, it is an extremely rich country entomologically, and investigation of its forest fruits for fly parasites should be profitable.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 16, 1936, TO DECEMBER 10, 1936.

Date		Per Pound	Per Ton	Remarks
Sept.	16, 1936	3.61¢	$72.20	Cubas.
"	17	3.555	71.10	Puerto Ricos, 3.55; Cubas, 3.56.
"	18	3.505	70.10	Puerto Ricos, 3.50; Cubas, 3.51.
"	21	3.50	70.00	Various raws ex store.
"	22	3.46	69.20	Various, 3.45; Cubas, 3.46; Philippines, 3.47.
"	23	3.405	68.10	Cubas.
Oct.	1	3.40	68.00	Philippines.
"	2	3.35	67.00	Puerto Ricos, Philippines.
"	13	3.375	67.50	Philippines, 3.35, 3.40.
"	14	3.36	67.20	Cubas, 3.35; Philippines, 3.36, 3.37.
"	15	3.35	67.00	Cubas.
"	19	3.40	68.00	Philippines.
"	21	3.39	67.80	Puerto Ricos.
"	29	3.355	67.10	Puerto Ricos, 3.35; Philippines, 3.35, 3.36.
Nov.	2	3.40	68.00	Philippines.
"	4	3.55	71.00	Philippines, 3.50, 3.55, 3.60.
"	5	3.65	73.00	Puerto Ricos.
"	6	3.69	73.80	Cubas, 3.68; Philippines, 3.70.
"	16	3.65	73.00	Cubas, Philippines.
"	18	3.70	74.00	Philippines.
Dec.	1	3.85	77.00	Cubas.
"	2	3.81	76.20	Cubas.
"	10	3.78	75.60	Cubas.

THE HAWAIIAN PLANTERS' RECORD

Vol. XLI SECOND QUARTER, 1937 No. 2

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Phosphate Deficiency:

The photograph reproduced on the cover shows the early, greatly stimulated root and shoot development of sugar cane which results from the application of a phosphate fertilizer with the seed at the time of planting. Two other photographs appearing hereafter, verify and emphasize the fact that a lack of stooling is a rather definite symptom of phosphate deficiency, when the green color of the leaves indicates a sufficiency of nitrogen.

Variation in the Nitrogen Content of Irrigation Water Carrying Dissolved Nitrogen Fertilizer:

Recent observations of a certain degree of carelessness by operators applying dissolved nitrogen fertilizers in the irrigation water make timely the presentation of the results of a study which brings out the variations in the nitrogen content of such irrigation waters, and suggests our more careful consideration of the approved and more reliable procedure.

Better Planning for Field Experiments With Fertilizers:

Anticipating still further the practical difficulties in the handling of large field experiments conducted on a plantation scale, we present a timely discussion concerned with some of the considerations that need our best thought and attention when planning the fewer and better field experiments with fertilizers that will probably follow. The avoidance of faulty designs, the guidance from rapid chemical and Mitscherlich soil analyses, the use of preferred plans, and constant efforts to reduce the experimental error are becoming more and more important factors of our field experimental technique.

Observations and Impressions in East Africa:

Added to the glamour of being among the last outposts of the primitive, the countries visited by the author of this article have the importance of harboring rich and as yet very incompletely developed sources of raw materials. It is this last named distinction, which is of little interest to the naturalist, that is most likely to focus the attention of the world on East Africa on frequent occasions during the next few years.

Soil and Plant Material Analyses by Rapid Chemical Methods—II:

This article is a second contribution to "Soil and Plant Material Analyses by Rapid Chemical Methods," the first having been published in the *Record* in 1936.

Additional rapid methods of analysis are described which were developed to augment research by plantation and Experiment Station agriculturists and chemists.

Specifications are included for the construction of a laboratory suited to conducting R.C.M. studies. Formulae and instructions are presented for the preparation of reagents used in the determinations described.

The subject of color standards is discussed in some detail.

Phosphate Deficiency

The value of phosphoric acid in promoting an early and vigorous root and top growth, and in encouraging adequate stooling of grains and grasses has been definitely established. In the accompanying photographs we offer contrasts that make it unnecessary to describe further symptoms of phosphate deficiency on sugar cane.

The illustration on the cover of this issue shows (at the left) 2 single-eye seed pieces of H 109 cane that were planted in a phosphate-deficient soil and removed for photographing at the age of six weeks, and (at the right) 2 comparable seed pieces planted in the same soil but which had been fertilized with a phosphate fertilizer at the time when the seed was planted.

Fig. 1 shows H 109 cane growing in this same soil. The original stand in each lysimeter was secured from four eyes. In the pot marked "1—No P_2O_5" there has been an entire absence of stooling as well as a greatly inferior top growth, while in the pot marked "2—Super" the original stand has doubled and top growth has been quite satisfactory.

Fig. 2 shows another series of H 109 cane growing in small pots containing a "low phosphate" soil. The four original stalks that were established in the pot at the right are still there, but they have never stooled-out nor made much growth; they are merely existing in this soil which has not been fertilized with phosphate. In the center pot the same soil was fertilized with phosphate before the four shoots were planted, and the effect of this phosphate fertilization is visibly shown by the abundant stooling and growth which the cane has made. In the left-hand pot, the cane growth and absence of stooling was similar to that in the right-hand pot up to the age of 7 months; phosphate fertilizer was then applied and 3 months later the photograph was taken. This fertilization resulted in the greatly stimulated stooling and growth that is indicated, and although not equal to the development of the cane in the central pot, the phosphate deficiency symptoms (as shown at the right) are fast disappearing.

R. J. B.

Fig. 1. Comparative growth and stooling of sugar cane grown with phosphate fertilizer (No. 2) and without phosphate fertilizer (No. 1).

Fig. 2. Cane growth and development; pots right to left respectively: without phosphate, with phosphate from time of planting, and with phosphate application delayed for seven months after planting.

Variation in the Nitrogen Content of Irrigation Water Carrying Dissolved Nitrogen Fertilizer

By R. J. Borden and K. H. Berg

In *The Hawaiian Planters' Monthly* for February 1902, page 100, we find perhaps our earliest reference to the application of a soluble fertilizer in the irrigation water for sugar cane. J. T. Crawley who writes of a method of applying nitrate of soda *devised* and used by Manager W. F. Pogue, of Kihei Plantation, in 1901, quotes Mr. Pogue as follows:

> . . . I have just finished fertilizing some 600-odd acres with nitrate dissolved in water and applied in the irrigation. The form of application was as follows: Dilute one bag of nitrate of soda in one barrel containing 50 gallons of water, one pail of this solution is added to four pails of water, or in that proportion; in another barrel a hose bibb in the bottom of the last barrel discharges the diluted solution into a tub which is kept filled to a given mark, from the tub mixture flows in an exact amount all day into the main irrigation ditch. The outlet of the tub is fixed, and cannot be opened or closed by the laborer doing the work. Strainers are used on the tub and diluting barrel. . . . . It seems to me that any soluble fertilizers can be applied much more evenly and certainly very much cheaper than in the ordinary method [application by hand]. It also seems to me that . . . . the applications could be made in small doses as the cane needs it. . . . .

Commenting on this method used by Mr. Pogue, C. F. Eckart states:

> As the barrel from which the nitrate solution is discharged into the main ditch is kept at a constant level, an even pressure and discharge is obtained which would guarantee a regular and unchanging admixture of nitrate solution and irrigation water.

In his bulletin "The Irrigation of Sugar Cane in Hawaii," W. P. Alexander in 1923 gave us an excellent photograph and description of the procedure, of applying fertilizer in the irrigation water, that was then in use at Ewa Plantation Company. This is reproduced here as Fig. 1.

In more recent years, it has been observed that some operators have been letting the fertilizer solution run directly into the irrigation ditch from the barrel of mixed solution, without using the intermediary tub with its solution kept at a fixed level. Such a procedure is shown in Fig. 2 and the results of a recent study* which we have made indicate that this method may be quite unreliable for, unless extreme care is exercised, this method of distribution lends itself to considerable variability in the amount of solution flowing from the barrel, since the pressure head in the barrel is constantly diminishing.

To determine some measure of this variability that is likely to occur when nitrogen fertilizer is applied in water, a number of water samples were taken at 5-minute intervals at the heads of several cane lines. The samples were obtained in the ditch, well below the point where the nitrogen fertilizer solution was being added from a single barrel. Since the level ditch was on a one per cent grade, the flow of water therein was quite slow.

The technique of sampling was to collect each water sample by making 20 dips into the stream of running water with a small test-tube sampler at the point desired. The samples were taken in duplicate, i.e., two lines were sampled simultaneously.

* Project A-105—No. 77.

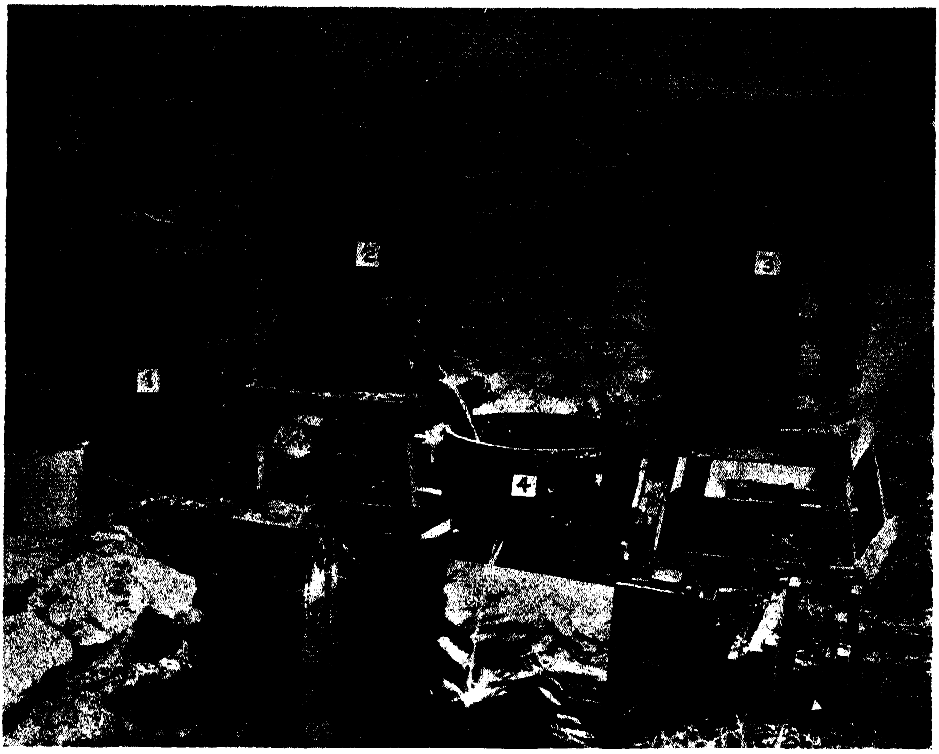


Fig. 1

"Fertilizer being applied in irrigation water. This setup of barrels is the standard method of applying nitrogen in solution at Ewa Plantation Co. Its proper use insures a steady and even concentration of the chemicals entering the ditch water at all times. In barrel 1 the nitrate of soda or sulphate of ammonia crystals are completely dissolved. Barrels 2 and 3 are made up to a fixed solution; for example, one barrel per one bag of 100 lbs. From here the solution runs into tub 4, and is so regulated that it is kept at a constant level. The opening into the ditch is so set that a known amount of liquid will enter the ditch during a known time, provided the level in tub 4 is not changed. If the solution entered the ditch directly from barrel 2 or 3, the pressure would diminish as the barrel emptied, resulting in a varying rate of discharge, first a rapid stream and then a smaller. It would be possible for one to regulate this by changing the opening constantly. Such a procedure however, cannot be done accurately. Again in refilling the barrel the concentration of solution will not be uniform. That is the reason for having two barrels. When one is being emptied, the other can be filled. Using this method the costly nitrogen fertilizer can be applied very uniformly in the irrigation water."

Hence Nos. 1 and 1A are duplicates, as are Nos. 2 and 2A, etc., and since the duplicates generally agree well, it is indicated that the technique of obtaining the water samples was sufficiently accurate.

A study of four such series was made and the resultant analyses of the amounts of ammoniacal nitrogen contained in the successive 5-minute-interval water samples show some rather large variations (Table I). When it is considered that the field that was getting this water was supposedly at all times receiving a uniform application (50 lbs. per acre) of nitrogen from the ammonium sulphate solution, these large differences are not indicative of any great degree of uniformity in the nitrogen application.

TABLE I

Ammonia Nitrogen in Parts per Million.

Elapsed time of sampling	Test 1 No. 1	Test 1 No. 1A	Test 2 No. 2	Test 2 No. 2A	Test 3 No. 3	Test 3 No. 3A	Test 4 No. 4	Test 4 No. 4A
0	48	48	28	36	5	5	36	36
5 minutes	48	36	36	36	2	2	48	48
10 "	36	36	12	12	12	12	48	48
15 "	36	36	12	9	7	7	48	48
20 "	48	48	5	7	48	48	36	36
25 "	36	36	9	9	60	60	36	36
30 "	36	36	9	12	72	60	28	28
35 "	28	28	36	48	72	72	28	20

A further part of this study was concerned with an attempt to ascertain whether or not the first few lines of cane next to the barrel of fertilizer solution were receiving any less nitrogen than the other lines, because it was conceivable that in this slow-flowing ditch, the irrigation water and the fertilizer solution might not be well mixed until after the water had flowed for some distance. The results of 6 tests, which are given in Table II, are apparently contradictory.

TABLE II

Ammonia Nitrogen in Parts per Million.
Samples in 10 Adjacent Lines Taken Simultaneously.

Cane Line	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
No. 1	9	96	100	36	3	12
2	9	96	60	9	28	20
3	7	180	60	12	28	20
4	7	96	60	36	36	28
5	15	180	60	28	48	36
6	15	96	60	48	36	36
7	28	180	60	28	48	36
8	20	140	60	48	48	36
9	20	140	36	28	60	36
10	20	100	60	36	48	36

Test No. 5 indicates that the first few lines nearest the barrel do not receive sufficient nitrogen, while Tests Nos. 6 and 7 would lead to a contrary conclusion. While Tests Nos. 8, 9, and 10 were being run, it was noticed (by using a dye with the fertilizer solution) that the position of the barrel on the ditch bank had an important effect on the amount of fertilizer going into the first few lines. The accompanying diagram indicates the position of the two barrels, "A" and "B," with respect to the cane lines being irrigated. (See Fig. 4.)

Tests Nos. 8 to 10 were taken while barrel "B" was being discharged. As a result, the first few lines seemed to contain generally less nitrogen than the succeeding lines. To probe this still further, additional tests were run while either barrel "A" or "B" was being discharged. These results are presented in Table III, and the figures apparently bear out the preceding observation: while barrel "A" was being discharged the concentration of nitrogen in the water samples taken simultaneously from the first 10 cane lines is practically equal; on the other hand, when barrel "B" was being emptied, the water from the first four lines showed less nitro-

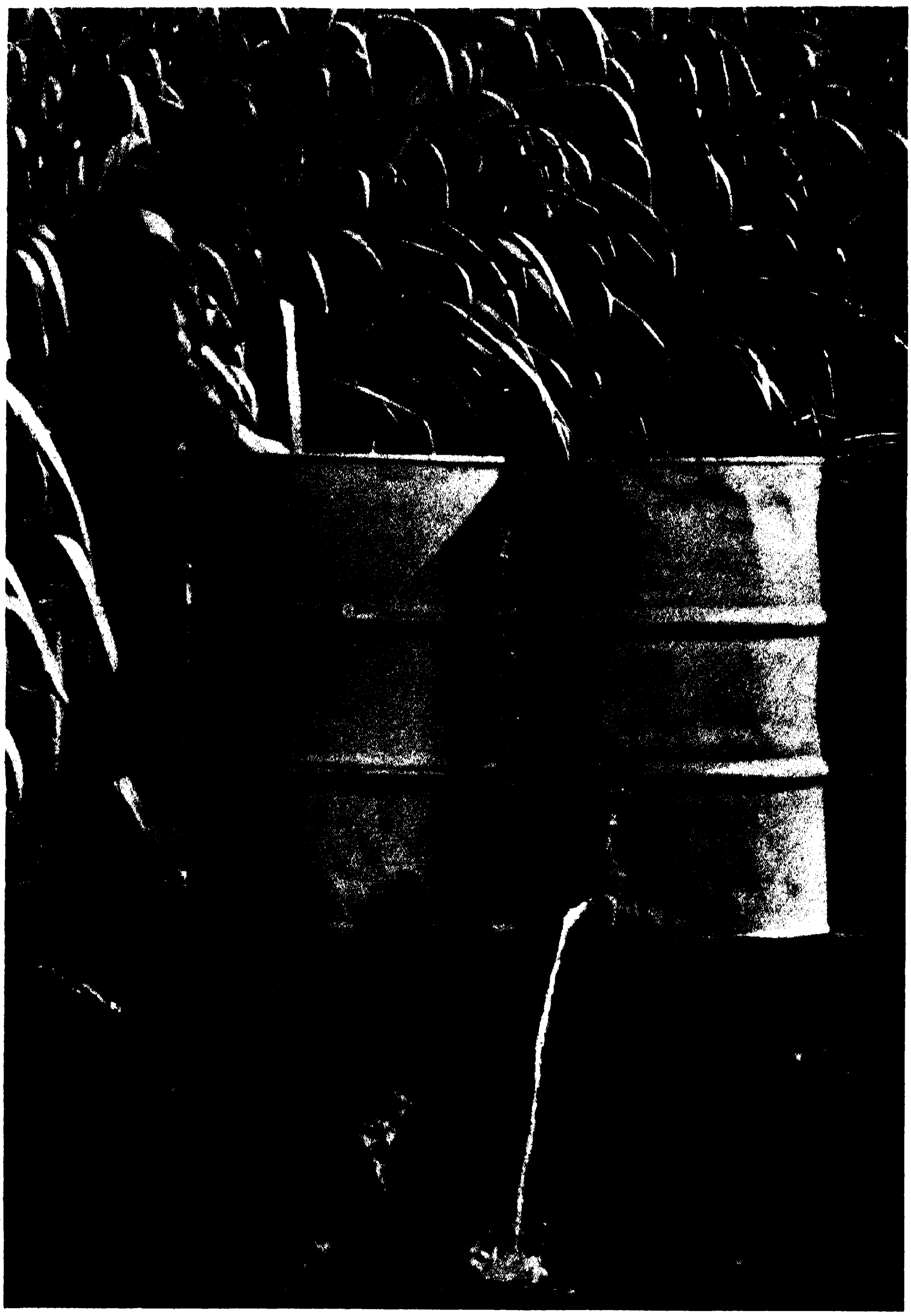


Fig. 2. An Unreliable Procedure.

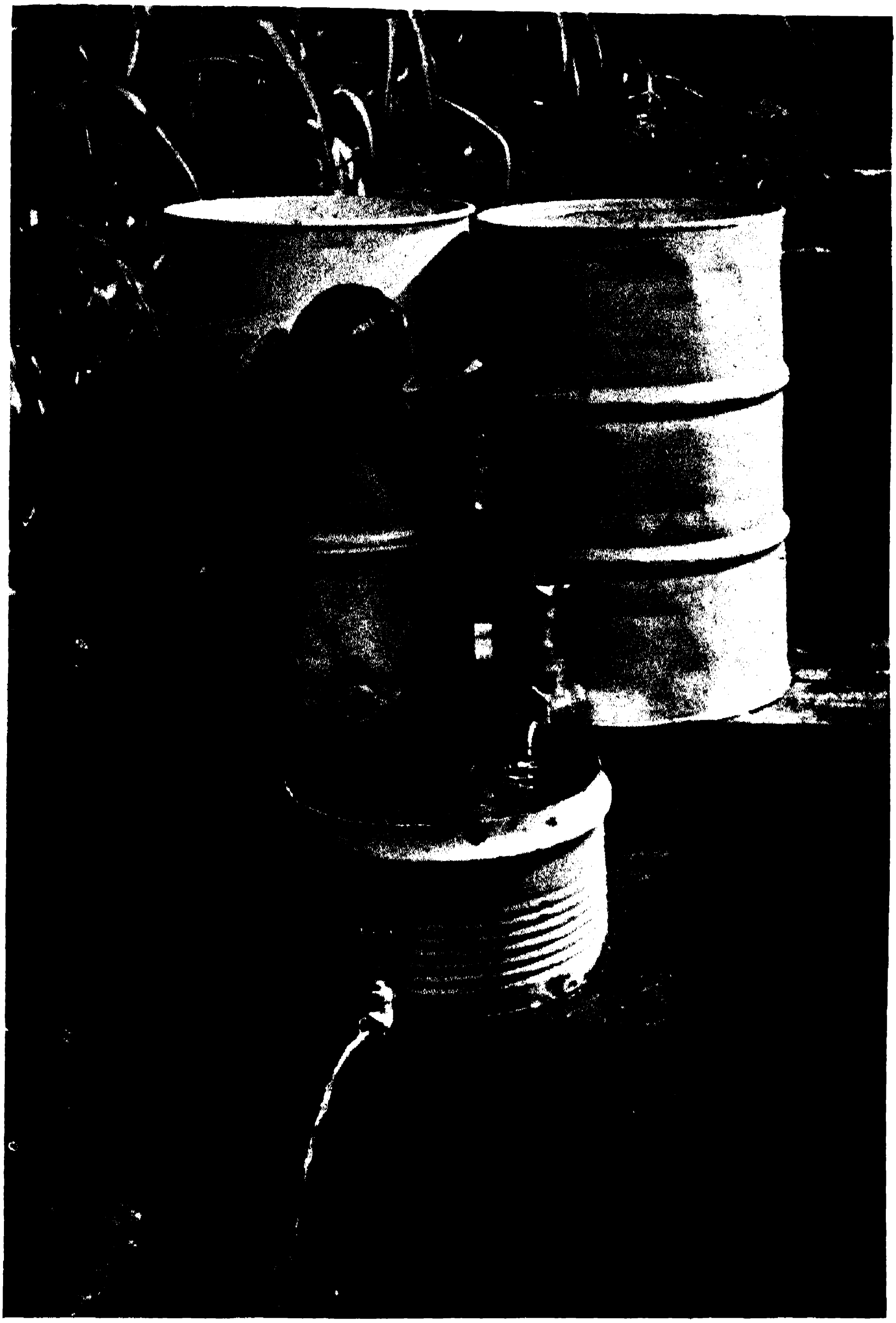


Fig. 3. An Approved and Reliable Procedure.

gen than samples from the succeeding ones. Incidentally, Tests Nos. 11 and 12 offer additional proof of the all-important influence of the pressure-head in the barrel upon the nitrogen concentration in the ditch: the last fourth of the barrel was discharging while those samples were being taken, and although the stream of fertilizer solution from the barrel outlet seemed to be of the same magnitude as from a full barrel, the analytical results show that the nitrogen in the ditch water was exceedingly low.

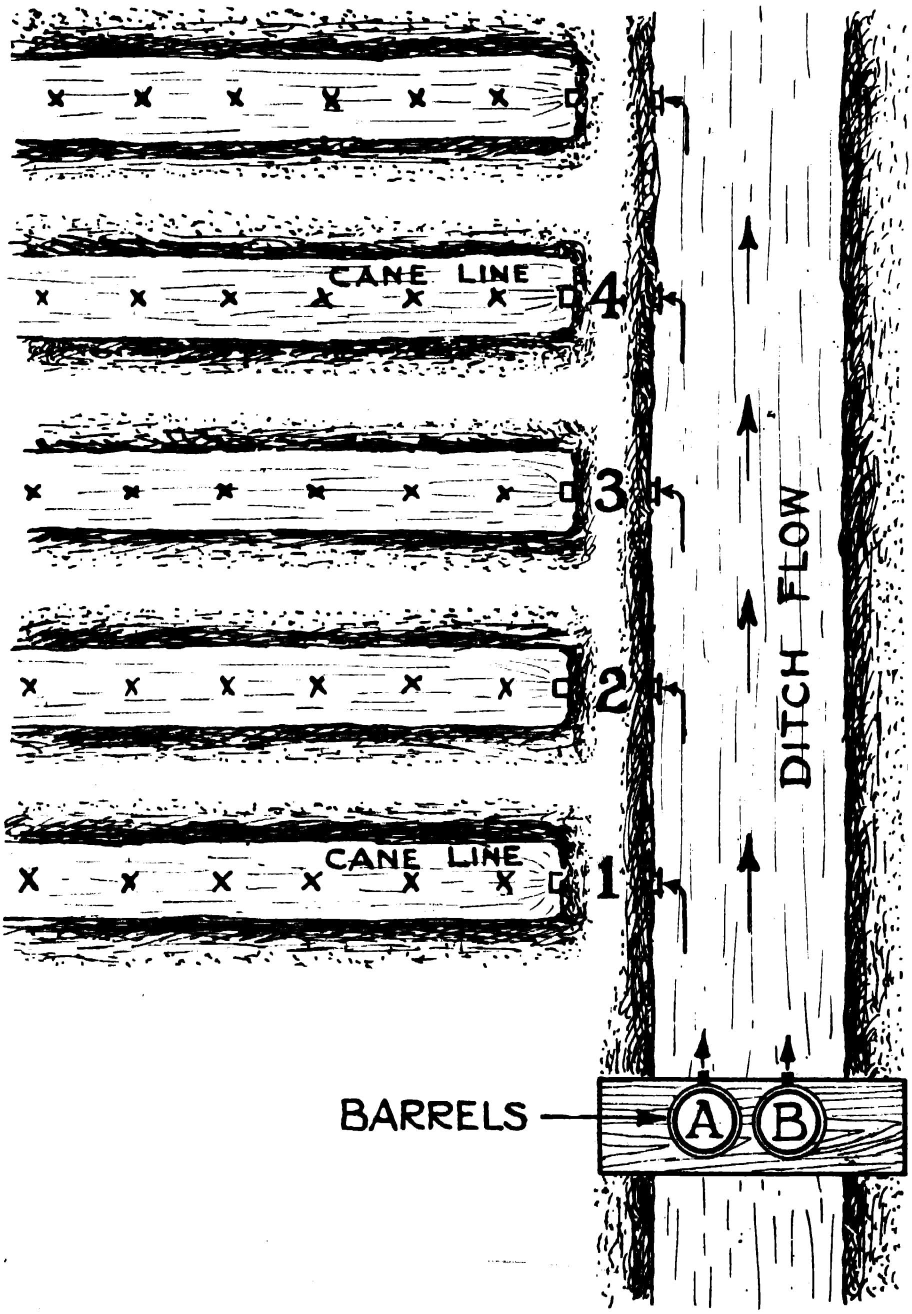


Fig. 4. Position of barrels of fertilizer solution with respect to cane rows being irrigated: "A" would be preferred to "B."

TABLE III

Ammonia Nitrogen in Parts per Million.
Sampled in 10 Adjacent Lines Simultaneously.

Cane Line	Barrel "A"		Barrel "B"	
	No. 11	No. 12	No. 13	No. 14
No. 1	7	15	1	1
2	7	7	20	15
3	9	12	20	12
4	7	7	20	20
5	9	7	36	36
6	7	7	36	36
7	7	7	36	36
8	7	5	48	36
9	9	7	48	36
10	7	7	48	36

When the procedure of delivering the fertilizer solution from the barrel to the ditch was changed from that shown in Fig. 2 to that shown in Fig. 3, and a constant head of solution was maintained in the final-discharge tub, an application of Chile potash nitrate (75 pounds of N and 70 pounds of K_2O per acre) was put on with a relatively even concentration throughout the first ten lines of cane, in two separate tests. These analytical results are given in Table IV.

TABLE IV

Cane Line	Test No. 15 Parts per Million		Test No. 16 Parts per Million	
	Nitrate Nitrogen	Potash	Nitrate Nitrogen	Potash
No. 1	90	90	80	90
2	90	90	90	90
3	90	80	90	80
4	90	80	80	90
5	60	75	90	80
6	90	90	90	90
7	80	90	90	80
8	90	90	90	90
9	90	75	90	90
10	90	80	90	90

The conclusions are perfectly obvious that, unless the better control and the approved technique (as shown in Figs. 1 and 3) for applying soluble fertilizer in the irrigation water are constantly used, we may well expect a very uneven distribution of such fertilizer material within the cane field, and from such an application a spotty cane growth can result.

Better Planning for Field Experiments With Fertilizers

By R. J. Borden

1—The Design

Statistical methods can help us not only to verify our opinion of the results from field tests but they can also guide us in our task of correctly designing an experiment. We can cite many instances wherein it has been found after the harvest results were secured that the particular experiment has shown "no differences," and a careful but belated examination of the design of the experiment has revealed an exceedingly small chance of detecting the effects which were likely to be met.

One of the first questions we must decide is, "What is the size of the difference between yields which we may be likely to detect in the experiment, if a difference exists?" It is quite possible that one treatment may be better than another but because of the random variation in the experiment, its advantage may not be detected. Also, how can we plan a test to assure a greater chance of detecting small differences when they do exist? An expenditure for an extra 50 pounds of nitrogen, or for an additional 100 pounds of phosphate or potash would be more than compensated for by the cash returns from an extra 2 tons of cane which might be secured (if the quality is not too greatly affected) and 2 tons of cane is certainly less than 5 per cent of our present-day average cane yield; so there is a real economic objective in seeking to measure such a small yield difference. Within the upper range of the treatment totals at which most of our fertilizer tests are run, yield differences of the nature of 10 per cent (7 tons on 70-ton cane) are seldom expected or found, for the law of diminishing returns is definitely effective and dominant. Hence we must prepare to measure the small differences that are definitely the result of the applied fertilizer treatments.

There are 3 ways in which this can be done: (1) We may use a less stringent level of significance, e.g., a probability of .05 (odds of 19 to 1) instead of a probability of .01 (odds of 99 to 1); (2) lower the probable error of a single plot by improving the experimental technique; and (3) increase the number of replications. The first method will increase the chance of detecting the advantage of "A" over "B" when it does exist, although it will also increase the possibility of a mistake when stating that "A" is better than "B." Many suggestions have been made available for ways to reduce the probable error of a single plot: plot arrangements for determination of positional variance; reduction of border effect; increased plot size; early correction of gaps in stands; closer supervision, and more adequate sampling. And we will need the increased number of replications to insure the reliability and to afford the means for a more nearly correct measure of the experimental error to compare with the so-called treatment error.

Table I has been prepared to assist the experimenter in planning his experiment and deciding whether the efficacy of the proposed test is sufficient.

To use this table, one will need to assume an expected per cent PEs for the experiment he is to install. An analysis of previous field experiments should give him

an approximate idea of what this figure may be. A study made in 1930 of all our cooperative field experiments showed an average PEs of 6.6 per cent, but we feel that this error has been somewhat reduced since that time, and we know that at some plantations it has recently been in the neighborhood of 3 to 4 per cent.

One must next "guess" at the size of the gain which may be expected from the proposed treatments, and here too, our past experience will be helpful. Generally speaking, we should seek to measure differences of the order of 5 per cent or less in our better fertilizer experiments.

Finally we should not be willing to accept a level of significance for our results, which is less than a probability of .05 (odds of 19 to 1).

TABLE I

Number of replications necessary to significantly measure differences (d) of the order of 10, 5, and 3 per cent when an approximate probable error for a single plot (PEs) can be expected.

Level of significance: P at .01
Odds 99 to 1

$$\text{Formula } n = \left(\frac{3.8 \times \text{PEs}}{d}\right)^2$$

Level of significance: P at .05
Odds 19 to 1

$$\text{Formula } n = \left(\frac{2.9 \times \text{PEs}}{d}\right)^2$$

Expected PEs	Difference to be Measured 10 Per cent	5 Per cent	3 Per cent	Expected PEs	Difference to be Measured 10 Per cent	5 Per cent	3 Per cent
15 per cent	32	..	..	15 per cent	19	..	..
12 per cent	21	..	..	12 per cent	13	..	..
10 per cent	15	..	..	10 per cent	9	34	..
9 per cent	12	..	..	9 per cent	7	27	..
8 per cent	10	37	..	8 per cent	6	22	..
7 per cent	8	28	..	7 per cent	5	17	..
6 per cent	6	21	..	6 per cent	4	13	34
5 per cent	4	15	40	5 per cent	3	9	24
4 per cent	3	10	26	4 per cent	2	6	15
3 per cent	2	6	15	3 per cent	1	3	9

An example: Assuming a PEs of 6.0 per cent for a proposed field experiment, and expecting to measure a difference of 5 per cent (from an expected 80-ton crop of cane) with odds of at least 19 to 1, we shall need to provide at least 13 replications. If we can conduct the test so as to reduce the PEs to 4.0 per cent, we can accomplish our objective with 6 replications; but if we wish to measure a 3 per cent yield difference from 9 replications we will need to reduce the PEs for the experiment to 3 per cent.

2—Phosphate Problems

In the planning of any field experiment that is concerned with a soil fertility problem, the rapid chemical method, the Mitscherlich test, and other indices of the supply of available nutrients in the soil should be made use of to more clearly determine the issue involved and to furnish the guide for the plan that is to be used.

Where the analytical indications point to a possible deficiency of phosphate, the chief issues involved are (1) how much to use, (2) what form is best, and (3) where and when to apply it for best results. Thus we have a choice of plans somewhat of the following nature:

Amounts of Phosphate:

Treatment Identity	Plans—Total Pounds P_2O_5 to be Applied No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
X	0	0	0	0	0	0	0	0	150	100
A	200	100	150	100	75	150	100	200	200	200
B	..	200	300	200	150	200	200	400	250	300
C	..	..	..	300	225	250	600	600	300	400

Until the response to phosphate has been definitely established for the area where the test is to be placed, a zero phosphate series of plots is quite essential, and plans like Nos. 9 and 10 are inappropriate.

Because of the difficulty in securing reliable measurable effects of small variations of applied phosphate fertilizers in a field test, the successive increment differences should seldom be less than 100 pounds, and a plan like No. 4 is to be preferred to Nos. 5 or 6, while No. 10 is perhaps better than No. 9. Certainly No. 6 with only 2 treatments: A and B, or B and C, would be wholly unsatisfactory.

In view of the fact that experience has shown that it is desirable to use large increment differences (100 pounds), it is quite likely that the optimum amount will best be arrived at by an interpolation of the harvested yield data. Thus it will be preferable to have 4 treatments included in an "amounts" test in order that a more nearly accurate yield curve may be constructed for this interpolation, and so plan No. 4 will be preferred to Nos. 1, 2 or 3.

For those soils where we find a high phosphate fixation, plans Nos. 7 or 8 would get our preference; the "C" plots might be carried on after the first crop without additional phosphate, in order to study the possibility of a residual benefit from the heavy initial application. Only on a few phosphate-deficient soils where the phosphate fixation is negligible would we want to use a plan with 50 or 75 pounds increment differences, and then only if there was one series with zero phosphate, and another series receiving at least 150 pounds of phosphate for comparison.

When the preliminary studies of the analytical data indicate that a response to phosphate fertilizer is unlikely to be obtained, tests which are designed to determine an optimum amount are not in order; the issue involved now becomes one of simply checking our decision to omit phosphate from the fertilization, and of watching the trend of yields on areas where we continue to omit phosphate as compared with adjacent areas where it is being supplied, perhaps for insurance purposes. Thus the most suitable test becomes simply a response test and Plan No. 1 is to be preferred.

Forms of Phosphate:

Such tests should not be installed until a response to phosphate has been obtained, or its deficiency has been definitely indicated.

The amount of P_2O_5 at which the various forms of phosphate are to be compared should not be excessive since the relative efficiences may be masked if the least efficient form is supplied in such quantity as to enable it to supply the crop with its full phosphate requirement.

We would prefer Plan No. 11 to No. 12:

PLAN No. 11

Identity	Treatment
X	No P_2O_5
A	200 lb P_2O_5 from superphosphate
B	200 lb from rock phosphate

PLAN No. 12

Identity	Treatment
A	200 lb P_2O_5 from superphosphate
B	200 lb P_2O_5 from rock phosphate
C	200 lb P_2O_5 from reverted phosphate

We would suggest consideration of Plan No. 13 where it is suspected that a calcium deficiency may cause a misinterpretation of the effect from a phosphate carrier like superphosphate or rock which both contain calcium:

PLAN No. 13

Identity	Treatment
X	No P_2O_5 or CaO
A	200 lb P_2O_5 from ammonium phosphate
B	200 lb P_2O_5 from superphosphate (or rock phosphate)
C	200 lb P_2O_5 from ammonium phosphate plus the calcium equivalent of super (or rock)

Time of Application; Also Place of Application:

Unless it is suspected that these issues are reasons for a failure to secure a response, tests such as these should be installed only on soils where a real response has been secured. Both Plans Nos. 14 and 15, either with or without treatment "C" are good ones, but they would not be so satisfactory without treatment "X."

PLAN No. 14

Identity	Treatment
X	No P_2O_5
A	200 lb P_2O_5 at planting
B	100 lb P_2O_5 at planting, 100 lb second season
C	100 lb P_2O_5 at planting, 50 lb at 3½ months, 50 lb at 7 months

PLAN No. 15

Identity	Treatment
X	No P_2O_5
A	200 lb P_2O_5 in off-bar (or subsoil) furrow
B	200 lb P_2O_5 on top of stubble
C	200 lb P_2O_5 broadcast between cane rows

General Considerations:

In any of these phosphate tests the amount of potash to be supplied, which will be similar for all treatments, will be quite reliably indicated by our R.C.M. tests and by former experience. It is only necessary that sufficient K_2O be supplied to make certain that it is not a limiting factor. Under conditions of heavy rainfall (150 inches), this may need to be at 250 to 300 pounds per acre, but on most of the irrigated lands, 200 pounds should be enough to insure against a potash deficiency. Similarly, nitrogen will be furnished at a total amount that is considered adequate for an optimum crop under the expected conditions.

Unless the time of application is a part of the issue being investigated, it is generally believed best that all phosphate which is to be used be applied as soon as

possible. This is especially desirable if the soil has a strong tendency to fix soluble phosphates at the surface, or if insoluble phosphates are to be used.

On fields which have in recent years had an application of filter cake by the plantation's usual procedure, we can expect to find considerable "spottiness" or a wide range in the amounts of available P_2O_5 in analyses of the soil samples from even small areas. As a general rule, however, most of such soil samples will not be phosphate deficient and hence "amounts" tests will not be suggested. This is quite fortunate because it will usually be extremely difficult to measure significant yield differences from varying amounts of phosphate fertilizer that might be applied to such fields. If, however, it is desirable to install phosphate tests of any nature under such conditions, we shall need to give attention to the installation of a considerably larger number of replications than we would ordinarily use, if we are to have any expectation of getting even just a fair answer from the test.

3—Potash Problems

As a general rule, only those cane land soils that have been formed under conditions of heavy rainfall, or which have been otherwise leached or very heavily cropped, are usually deficient in available potash. Under such conditions, after the rapid chemical analyses or the Mitscherlich test of a representative soil sample has indicated that we might expect a yield response to potash fertilizer, we may proceed to a determination of the optimum amounts, and the most efficient forms and methods of using potash fertilizers, and plans for such tests that are somewhat of the following nature will need our consideration.

Amounts of Potash:

Treatment	Plans—Total Pounds K_2O to be Applied												
	No. 1		No. 2			No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Identity	1a	1b	2a	2b	2c								
X	0	0	0	0	0	0	0	0	0	100	150	150	200
F	150	200	100	125	150	125	100	75	150	200	225	250	250
G	..	..	200	250	300	250	200	150	200	300	300	350	300
H	..	..	..	..	..	375	300	225	250	400	375	..	350

Plans Nos. 7, 8, 9, and 10, without zero potash plots, would not be used until an experiment on the area under test had definitely established a response to potash greater than the minimum amount proposed for the "X" plots.

In order to provide sufficient data for reliable interpolation, a 4-treatment plan like Nos. 3 or 4 would be preferred to a 2-treatment plan like No. 1, or to one of the suggested 3-treatment plans shown above as No. 2.

Results from Nos. 5 and 6 should be capable of reliable interpretation, providing the zero potash ("X") plots are included, but either plan used with only two of its treatments: F and G, or G and H, would not be satisfactory.

When a response up to 150 or 200 pounds of potash has been definitely obtained, Plans Nos. 7 and 8 may be used, both being preferred to No. 9 if sufficient area is available for an adequate number of replications for all 4 treatments; otherwise No. 9 would be the more desirable. Plan No. 10 will seldom be satisfactory since its amounts are pretty well up to a point where the law of diminishing returns for

potash will operate and cause only small yield differences that will be difficult to measure with any great degree of reliability.

When we have found a reliable and dependable indication that an ample supply of potash exists in the soil or irrigation water, which will make it unlikely that a response to supplementary potash fertilization can be secured, our Plan No. 1 will be all that is necessary to enable us to check our decision to omit potash fertilization and to watch for any adverse yield effect of such a decision.

Only when a response to potash has been obtained should we give serious consideration to comparative tests of the efficiency of various potash carriers ("forms"), or of issues dealing with time and methods of application. And in any tests of this nature, it will be wise to include a "zero" potash series of plots.

In all potash tests, we should be sure that phosphate will not prove a limiting growth factor. If there is any doubt about the phosphate requirement, it will be wiser to apply 150 to 300 pounds on low and high phosphate-fixing soils respectively than to leave an opening for criticism when the results are interpreted.

On fields where molasses has been applied for the benefit of the immediate crop, or when "mill water" is being used for irrigation, it will be extremely hard to secure consistent yields. Hence one should avoid plans wherein the expected yield differences from the various potash treatments are likely to be small ones; and it goes without saying that the number of replicates should be quite largely increased if field tests are to be installed on such conditions.

Although definite proof is lacking of a loss of potash from applied fertilizer by leaching from all soil types carrying a vigorously growing cane crop, we have measured such leaching from some soils and conditions. Hence it is undoubtedly a much safer procedure in all field experimental work to apply potash, where it is to be used, in single applications of perhaps not over 150 pounds K_2O per acre than in much larger amounts.

4—Nitrogen Problems

It is no simple matter to plan good nitrogen field experiments, for the issues involved are both numerous and complicated. In contrast to phosphate and potash experiments, a definite response to an application of nitrogen on cane is almost always secured, and the major problem becomes one of determining the optimum amount to be used. Since nitrogen is the most costly of our fertilizer ingredients its own economy must be considered; and since it can generally be shown that too much nitrogen results in "more cane with less sugar," a still further question of crop economy is involved.

As far as we know, there is no such build-up or residual carry-over in the soil of surplus applied nitrogen as there is of surplus phosphates, and hence we must consider the effects only upon the particular crop on which the nitrogen fertilizer is applied. Since the conditions under which successive crops are grown are scarcely ever identical, the effects from similar amounts of nitrogen fertilizer that may be applied are almost certain to be variable. Differences in crop length from 12 to 30 months will certainly affect the optimum amount ~~of~~ nitrogen that can be assimilated, but I do not believe that we have as yet proved whether this amount will be in the nature of a straight-line relationship like "A" in Fig. 1, or a relationship more like that of line "B."

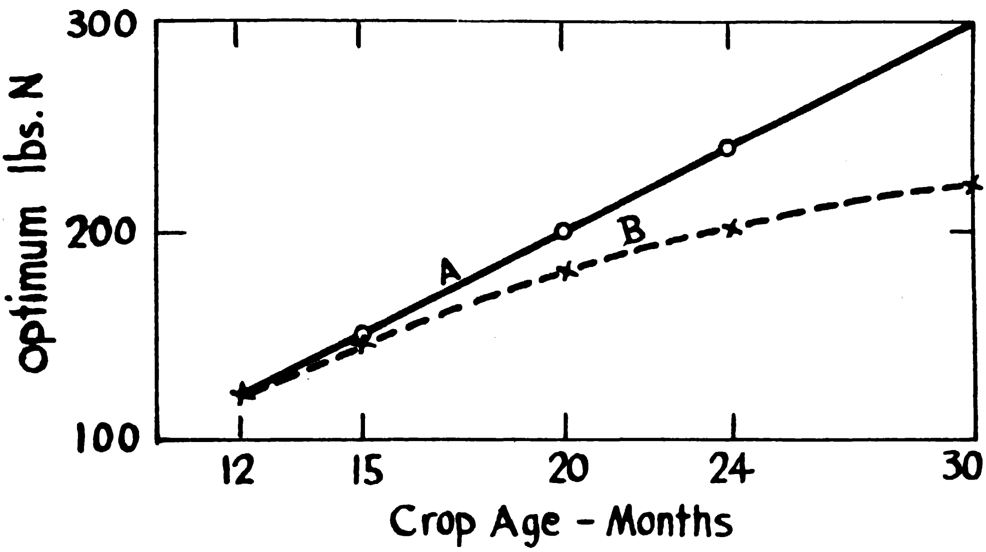


Fig. 1.

Differences in the uncontrollable yearly climatic conditions that frequently affect the cane yields as much as 20 to 30 tons will undoubtedly result in a difference in the economic utilization of a standard application of nitrogen fertilizer. Differences in the available supply of nitrogen, which will be greatly influenced by differences in soil moisture and in the amounts of organic matter and the conditions for its oxidation, will change the basic testing environment still further. Variety changes, perhaps changes in cultural practices, and quite likely changes in the time or the stage of development of the crop when the nitrogen fertilizer is applied will cause still more complication. Hence in our effort to find the optimum amount of nitrogen for our cane crops we must recognize these many factors that can influence such an optimum. Only by careful study of results from a series of well-planned nitrogen tests, conducted continuously so as to sample many cropping conditions, can we be assured that our interpretation of their results is most likely to be sound.

At the present time, we are not entirely sure just how to make use of R.C.M. or Mitscherlich analyses for available soil nitrogen, when planning field tests to secure an answer to the many nitrogen problems we may wish to investigate. Hence we are forced to intelligent reasoning and the utilization of what previous experience is available, meanwhile maintaining an open-mindedness towards many plans which are being used.

Amounts of Nitrogen:

In Fig. 2 we show two yield curves that illustrate the "law of diminishing returns." It is quite clear that the expected yield differences at the upper end of the curve between successive amounts of N are quite small as compared with those at the lower end. It becomes apparent at once that since the usual amounts of nitrogen which we supply in our N experiments are seldom less than 100 pounds, and that the optimum amount is usually to be found somewhere between 150 and 250 pounds, within which range the expected cane yield differences are quite small (and where

the negative relationship between cane yield and cane quality is likely to become a factor) we are going to have to design experiments that can be expected to measure these small yield differences with real significance.

We shall first need to consider the range of the nitrogen totals, the size of the increment (the nitrogen variable), and how and when this variable is to be supplied. We have some guidance from our past experience: Seldom have we found a crop that was not benefited by at least 75 pounds of total nitrogen but only in rare cases will the economic response exceed 300 pounds; nitrogen variables of less than 50 pounds (and we would consider 40 pounds as the absolute minimum), when these bring a nitrogen total above 150 pounds are exceedingly difficult to measure the effects of, and are to be discouraged.

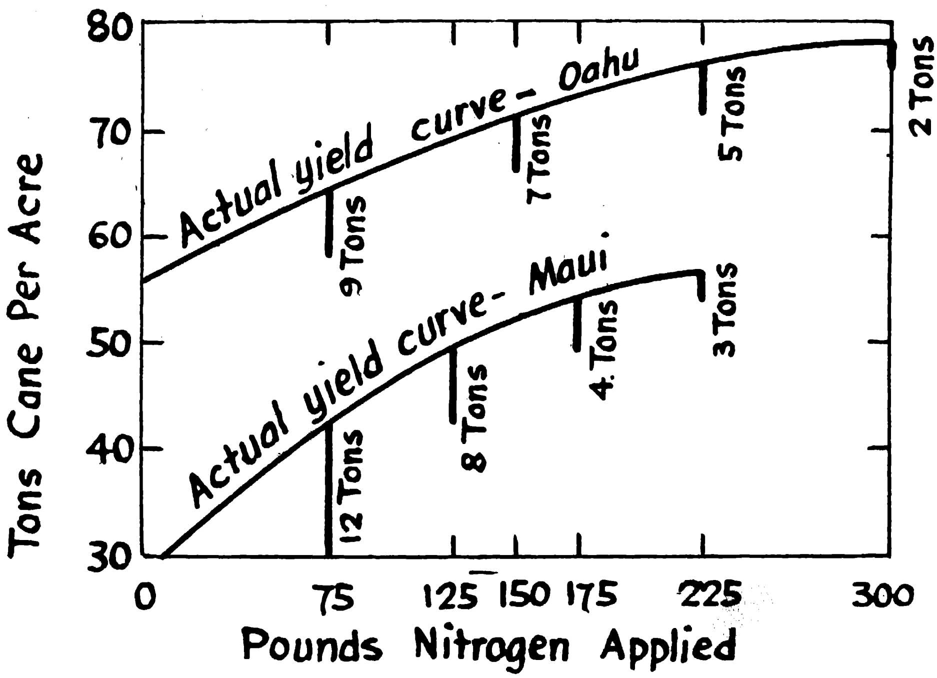


Fig. 2. Illustrating the law of diminishing returns.

The most debated point, for which there are many opinions but very few facts, is concerned with how and when the nitrogen variable is to be supplied. Our "Time of Application of Nitrogen" tests have not given us consistent results, so they cannot help us much. We have, however, some knowledge of certain facts which we believe may have some significance. Let us consider a few of them:

1. Analyses of the cane plant up to the time the crop is 3 months old have shown that only a very small amount of nitrogen has been taken up by this time; hence the need for supplementary dressings of N in the first few months is not very great. These same analyses have also indicated that the demand for nitrogen is especially heavy and that the uptake is very rapid from the time the cane "begins to make stalk" through the rest of its "first season."

2. Plant physiologists have indicated that there can be a translocation of absorbed nitrogen within the plant system, hence we might expect that surplus nitrogen

that is taken up during the "boom stage" would be available for second-season growth. We do not know whether or not such stored-up nitrogen has the same efficiency as a newly absorbed supply from a second-season application.

3. When a soluble nitrogen fertilizer is applied to a soil, it is made available not only to the cane but to the weeds and to all of the soil organisms as well. The greater this competition, the less nitrogen the cane crop gets at the time (and perhaps eventually also). But since it has been shown that the cane plant can take up nitrogen very rapidly when it has developed a large root system as compared with a root system which is only just being formed, we have knowledge that enables us to greatly reduce the length of this competitive period.

4. Ammonia nitrogen on an acid soil is just as subject to loss by leaching as a nitrate fertilizer. The loss of both forms by leaching is, however, quite negligible if the application is made to the crop after it has formed a well-developed root system.

And so we find quite a number of acceptable plans, none of which with our present knowledge can be given a preferential rating on other than personal opinion.

Usually the "Amounts of Nitrogen" tests carry three treatment variables and the objective is one of determining the reliability of the yield difference between (a) the mid amount and the low amount, and of (b) the high amount over the mid amount. When four variables are included, it is often possible to make a reliable interpolation and to secure the more nearly optimum amount therefrom.

The application of the nitrogen differential in water is to be discouraged, but if it is necessary then we must recognize that this method will be apt to greatly increase the experimental error and hence we shall need additional replications to offset (distribute) such error. Such added replicates of the treatments will also be called for when nitrogen tests are installed on land that has recently been treated with molasses or filter cake, since such treatments are also likely to increase the variation within a series of test plots.

R.C.M. and Mitscherlich analyses will indicate about how much P_2O_5 and K_2O should be supplied to all plots in the nitrogen test, so that neither P nor K will be a limiting growth factor.

Such plans as these should be quite satisfactorily adapted to most conditions:

PLANS—TOTAL POUNDS N

Plots	No. 1	No. 2	No. 3	No. 4	No. 5
A	75	100	125	120	160
B	125	150	175	180	200
C	175	200	225	240	240
D	225	250	275	300	. . .

Nos. 1, 2, 3, 4 may be used either with or without "A" or "D."

Herewith are eight examples of how the differential in Plan No. 2 (without Treatment A) might be applied.

Total pounds N split into 2 to 4 applications as indicated:

Plots	Total ℔ N	No. 2a	No. 2b	No. 2c	No. 2d
B	150	50–50–50	50–50–50	50–50–50–0	50–50–50–0
C	200	66–67–67	50–75–75	50–50–50–50	50–50–50–50
D	250	83–83–84	50–100–100	50–50–75–75	50–50–50–100

Plots	Total ℔ N	No. 2e	No. 2f	No. 2g	No. 2h
B	150	50–50–0–50	50–50–50	50–50–50	75–75–0
C	200	50–50–50–50	50–100–50	50–100–50	75–75–50
D	250	50–75–75–50	50–150–50	75–125–50	75–75–100

Next in importance to "Amounts of Nitrogen" will probably come "Time of Nitrogen" tests, and here many problems present themselves for better answers than we have at present, e. g.:

What proportion of the total N should be applied respectively in the first season and in the second-growth seasons; what proportions should be furnished before, during, and after the boom stage; how will these proportions be influenced by such factors as the (a) time of starting crop; (b) time of harvesting crop; (c) quality of the preceding crop; and (d) organic matter left by preceding crop.

Such a question as the relative effectiveness of 100 to 150 pounds of N applied in a single dose as compared with 2 or perhaps 3 doses, when given at different stages in the development of the crop has not had a satisfactory answer. Whether an extra 50 pounds of nitrogen is more effective in the early months, or during the boom stage, or at the beginning of the second season, is still a moot point, as also is the point of whether the season of the year or the stage of crop development is the dominating factor of "Time of Application of Nitrogen" tests.

In "Forms of Nitrogen" tests, the total amounts at which the various forms are compared should, if anything, be somewhat less than the optimum amount for the crop to be grown; unless this condition is provided, the least efficient form may be able to supply sufficient N for the crop and hence the comparative efficiencies will not be found. Perhaps the safest way is to include a series of check plots with the standard form at 50 to 75 pounds less than the amount at which the various carriers will be compared, e.g.:

X—N from ammonium sulphate with 125 pounds total N.
A—N from ammonium sulphate with 175 pounds total N.
B—N from nitrate of soda with 175 pounds total N.
C—N from urea with 175 pounds total N.

Little is known of the relative merits of nitrogen fertilizer placement for sugar cane. On cultivated lands, if the efficiency of the nitrogen when applied in the row-middle is equivalent to its application on the cane line, there is something to be gained through the former procedure.

Summary

Many of our field experiments still fail to answer clearly the question we have asked of them. Too often this failure is due to a faulty design that has been used, which under the conditions of the test has provided but little likelihood that a reliable answer could be secured. Especially when planning the design for the field experiment we do need to recognize that (1) the expected size of the uncontrolled variation (the probable error of the single plot yield), (2) the expected maximum amount of yield difference that will most probably be obtained from the applied treatments, and (3) the degree of significance (odds) which we are willing to accept as indicative of a real effect of this treatment, will all determine the number of replications that must be provided for in the layout.

Since the rapid chemical methods of testing soils have been made available and satisfactory qualitative answers to soil fertility problems are thereby more easily obtainable *before* the field test is actually installed, the main issues for the fertilizer field experiment will be concerned with (1) the determination of the optimum amounts, after indications of nutrient deficiency have been secured, and (2) the establishment of simple verification tests wherein the objective is to note any trend towards reduced yields caused by omitting some particular plant food, when the soil analyses have indicated a great sufficiency of same. For the former issue, plans that carry preferably four but not less than three treatment-variables are desirable; for the latter issue, a test with only two variables is sufficient.

Since many years of experience have indicated the difficulties that are generally concerned with measuring the effects of small increment differences on cane yields, certain minimum increments are suggested and acceptable plans for "Amounts" tests with phosphate, potash, and nitrogen are offered.

When the experiment is to be concerned with such issues as (1) the best form or carrier of a certain nutrient, (2) the optimum time for its application, or (3) the placement and methods of applying the fertilizer, it will be best to precede such test with one to determine definitely the need for the particular nutrient, unless such need is to be determined in conjunction with the other issue.

The analytical results from the rapid chemical methods of soil testing can be extremely useful in indicating the amounts of the other plant foods than the one being tested, that will need to be supplied so that they do not become the limiting growth factors.

Finally, it is economically sound that we plan field experiments that will measure relatively small yield differences between the applied treatments. If we depend too largely on a still further increase in the number of replications to do this, we will soon have an experiment that is quite impractical to handle. Hence it is apparent that our constant attention must be focused on those efforts to reduce the so-called "experimental error" which we know can be and has been reduced when the true and full value of reliable results is realized.

Impressions and Observations in East Africa

By F. A. Bianchi

It was my good fortune recently to take part, with Noel H. Krauss of Honolulu, in an expedition organized by the U. S. Department of Agriculture to search for enemies of the Mediterranean fruit fly. My services were lent for the purpose by the Experiment Station of the H.S.P.A. for a period of one year, and during that time, from September 1935 to October 1936, I spent eight months in four different countries of the African Continent. These included, besides Egypt, Sudan, Aden, and French Somaliland which were only touched in transit, the Mandated Territory of Tanganyika, the island Sultanate of Zanzibar, and the Colonies of Kenya and Uganda.

Of each of these countries I here offer those of my more salient impressions which I believe should prove of greatest interest to the readers of *The Hawaiian Planters' Record*.

Tanganyika

Our first stop in the territory once known as German East Africa, and our headquarters for the first two months of our trip, was the port of Tanga, six degrees south of the equator.

Founded by Germans on the site of an earlier Arab settlement, Tanga is situated on the edge of the Tanga Plains, a vast plateau which slopes gently upwards from the ocean to the easternmost range of the Usambara Mountains, more or less parallel to the coast on the N. E. corner of Tanganyika. Because the majority of its more substantial buildings face the completely enclosed bay, strung along unevenly on one side of a long street parallel to the shore, it welcomes the new arrival, while his boat still swings at anchor, with an impression of size that rapidly disappears upon closer contact with the reality of the case. As the ocean terminal of the important Tanga Railway and the center of a large sisal planting district, Tanga is nevertheless, one of the three or four principal towns of Tanganyika. As such it is amply furnished with fair hotels and well stocked stores and thus provided our expedition with headquarters which in comfort, if not in artificial entertainment of any sort, greatly exceeded our expectations.

Around the town and encroaching upon it in several places is found a thick fringe of coconut palms. Beyond this, the Tanga Plains are an almost uninterrupted extension of sisal plantations. Trees can be found only in scattered copses which mark either the sites of dwellings or the courses of streams. In the first case they are almost exclusively of introduced varieties and include for the most part fruit trees, mangoes, tropical almonds, cashews, citrus, papayas, sour sops, and others. In the second case, and that of small scattered areas unfavorable to agricultural development, the flora is remarkably rich and forms tangled and almost impenetrable masses of vegetation, among which even today are left remnants of valuable timber. Mvule, *Clorophora excelsa*, is at once the most common and the most useful of the

timber trees. Old timers averred that much of the land now given to the cultivation of sisal had been covered within their memory by flora of this type.

Prominent features of the landscape are spectacular specimens of *Adansonia digitata,* the baobab, which, as is often the case with the ceiba, *Ceiba pentandra,* in Central America, are occasionally left standing in cultivated areas. The baobabs with their bottle-shaped trunks are often remarkably large and handsome. Their seeds, closely packed within hard cases the size of a coconut, are embedded in a mealy pulp which is pleasant to the taste and from which can be extracted tartaric acid. Natives are fond of sucking them; and for some reason I did not ascertain, they also seem to have considerable attraction for an insect closely resembling in appearance, and almost rivalling in abundance, the well known box elder insect of the western United States.

Fringing the shores of the bay, wherever the slope of the land permits, is a belt of vegetation whose main component, *Rhyzophora mangle,* the mangrove, is well known in other tropical lands. Natives are often seen busily cutting and bundling the sticks of this plant for sale to Arab sailors who in Dhows—vessels of forbidding design—take the load to Arabia where the mangrove cortex is used in tanning and the sticks in the making of tents and firewood.

The larger game of the Tanga Plains, once probably as abundant as anywhere in Africa, has been almost exterminated, partly by man and partly by disease, but occasionally even now a lion, a leopard, a rhinoceros, or a buffalo is killed by some

Baobab tree, Tanga, Tanganyika.

week-end hunter within twenty or thirty miles of his home. Bushbuck, principally, and a number of other antelope species can still be easily obtained, and monkeys, mostly baboons and a long-tailed Cercopithecus species locally called Bastard Colobus, are very plentiful even in the immediate vicinity of dwellings where their wanton destruction of native gardens often assumes economic importance. Almost any afternoon walk is likely to bring one into the midst of a band of these remarkably tame animals. An African acquaintance of mine by imitating their peculiar chirping noises could walk up within arms length of them at any time.

Snakes, although I met only one, are said to be uncomfortably common everywhere, even within the town of Tanga itself. They include the dreaded black mamba, the puff adder, and an occasional python. On one occasion I barely missed seeing a python which had been found a few blocks from our hotel completely filling with its coils a freshly dug hole for a telephone pole. In their excitement the native electricians had failed to capture the animal, which, as nearly as their nervous description permitted me to judge, must have been 20 feet long.

Monitor lizards *(Varanus niloticus)* are occasionally found in the bush. Facially they resemble a python, but in the noise of their retreat through bush, no matter how impenetrable it may seem to a mere human, they show close kinship to a hurricane. They are said to be harmless, but having their five-foot length squirm between one's legs at a rate of twenty miles an hour, an experience I barely missed, might have painful consequences.

Small mammals like the cerval cat and mongoose are common, and particularly abundant and conspicuous in Tanga itself is a small lemur-like animal, *Bdeogale tenuis.* Often on moonlit nights dozens of these creatures can be heard chasing each other in wild gambols over the roofs of the town and their call, much like the wordless imprecations of an angered peacock, is on certain nights repeated with annoying persistence; otherwise, apart from the fact that they steal fruit, even entering open windows to do so, they seem to be harmless.

The insect fauna although not lacking interest for an entomologist might seem unexciting to the layman if it were not for the predominance among its more obvious constituents of Culicid and Anopheline mosquitoes. Coupled with a practically universal absence of screening, these pests constitute Tanga's only seriously annoying feature. To sit in the hotel lobby after dinner was a nerve racking performance for which, during most of our stay in Tanga, the majority of our fellow guests usually substituted the easier course of retiring early to bed. All beds in Africa are supplied with tent-like mosquito nets the edges of which can be tucked in under the mattress.

While investigating "ex officio" the sources of Tanga's mosquitoes I found that one of them was provided by the coconut plantations which surround the town. In contrast to the custom of natives in Hawaii and other countries, Africans usually dig permanent footholds into the coco palms; and each of these, worn in time by use and weathering, eventually becomes a receptacle for rain water ideally suited to the breeding of mosquitoes.

After dark, mosquito boots are worn generally by Europeans both men and women. Practically no one, however, of the people I met in Tanga had escaped the ravages of malaria. Among the natives, according to one of the local doctors, the incidence of the disease reaches practically one hundred per cent.

The fringe of coconut palms which surrounds Tanga. (Photograph by N. H. Krauss.)

Sisal fibre hung up on wires to be dried by the sun, near Tanga. (Photograph by N. H. Krauss.)

Flies are next to mosquitoes in the scale of "nuisance value." Species of Tabanus, Stomoxy, and Musca all exceed by far the reasonable limits of abundance to which a traveller becomes accustomed in other parts of the world; so much so that many natives, and some Europeans as well, practice the habit of always carrying a fly-chaser in their hand. This consists of some animal's hairy tail, and it is often provided with an elaborately artistic handle carved from wood or made of closely strung colored beads woven into a pattern.

Though it is scarce and I never saw it in Africa, *Scyphophorus acupunctatus,* a Rhyncophorid which has recently made its appearance in Hawaii, is of some importance to the sisal growers of Tanga. I was told that one single larva, if it bored sufficiently deep into the spindle, would cause cessation of growth and eventual death of the whole sisal plant.

The visitor in Tanga is struck by the pronounced scarcity of the larger domesticated animals. Climate and a number of stock diseases, including the well known Nagana, make the raising of cows and horses almost impossible. Of the former there is a small herd which supplies a limited quantity of poor quality milk to the European households of the town, but of the latter I saw not a single specimen anywhere in Tanganyika. Burros, also not very common, were sometimes seen taking the place of the horse.

Dogs in pleasant contrast to the case of some other tropical countries are also scarce. Disease is a factor in the reduction of their numbers, and in addition the possession of and contact with them are contrary to the tenets of the Mohammedan religion, to which most natives belong.

Chickens are raised by every native household and so are goats which take the place of the less hardy and completely absent sheep.

During the course of our stay in Tanga several visits were made by both members of our expedition to the East African Agricultural Experiment Station. This institution, well known through its scientific work, yet seldom visited because of its remoteness from the more frequented travel lanes of the world is known in East Africa as "Amani" from the native name of its location, and is situated on the very rim of the East Usambara Mountain some 2700 feet above sea level. Formerly there existed a narrow-gauge railroad to negotiate the 45 miles that separate the station from Tanga; but today, guide books to the contrary notwithstanding, that rail line has been dismantled and there is left only a regular dirt road which is likely not to be passable on extra-rainy days.

Although supported in part by direct contributions from the Tanganyika and other East African Governments, Amani is distinctly an Imperial institution entirely free administratively from local control. Its main purpose is the conduct of basic research in the problems of tropical agriculture such as is beyond the practical scope of the various colonial departments of agriculture.

On grounds that cover more than a thousand acres, a large part of which is still a practically virgin forest, the Station has a remarkably up-to-date scientific library and shop facilities that enable it to meet almost any demand in the line of scientific or domestic paraphernalia. It produces its own gas and electricity, and a considerable part of its food requirements, and it has been entirely responsible, of course, for the erection of the very solid and handsome buildings it occupies. These are

beautifully located in the midst of well kept gardens, and they are so extensive that they could easily accommodate a much larger staff than the ten men who now carry on their researches within their walls.

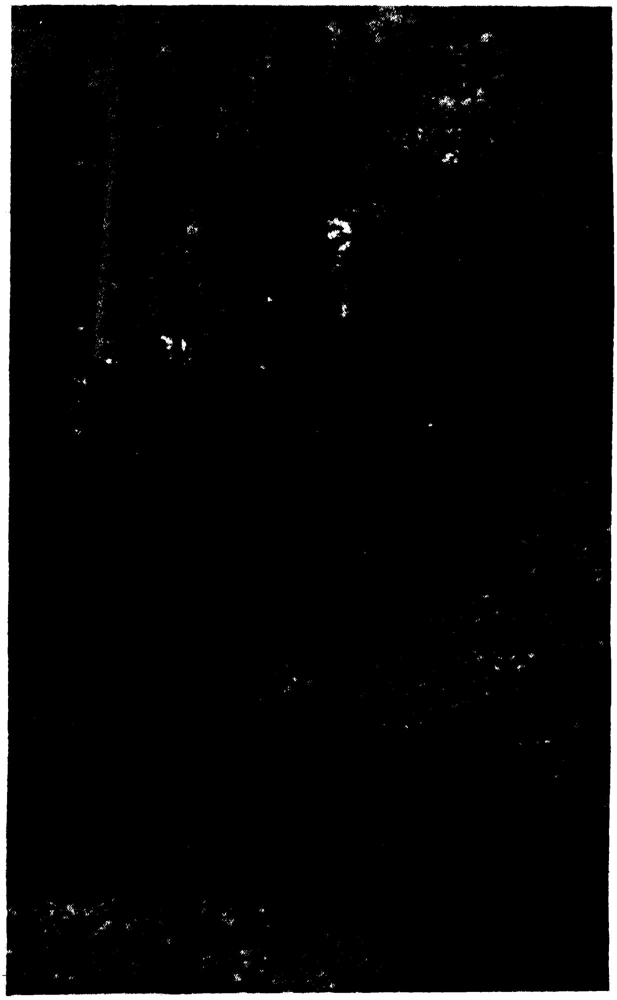
Mr. Kirpatrick, the Station Entomologist, was at the time of our visit very busy with the study of a remarkable Stylopid parasite of Antestia, a pentatomid bug which ranks first among the coffee pests of Tanganyika. We were told that the parasite was a chance discovery made by Mr. Kirpatrick during a visit to Arusha, a distant district, and that it was in several respects an extraordinary insect. Not the least extraordinary feature of it, in view of the fact that in the laboratory this Stylopid reproduced prolifically, was the fact that it had not been found earlier during the many years that coffee has been grown and studied in Arusha.

Agave amaniensis, Amani, Tanganyika. (Photograph by N. H. Krauss.)

Shortly before our visit the Amani Station had taken over the management of a neighboring coffee plantation of 8 or 10 thousand acres and it was, as an unprecedented activity in its history, undertaking the practical application of scientific methods to the culture of coffee. In this effort it was seriously handicapped by the nature of the soil in the region of the Usambara Mountains. Being extremely old geologically, this highly acid soil is unsuited to the requirements of coffee production. It is no wonder, therefore, according to W. Nowell, Director of Amani at the time of our visit, that one by one all the coffee plantations in the Usambaras, most of them founded before the war by Germans, have deteriorated to the point of bankruptcy, and that today one of the main objectives of the Station is to find suitable substitute crops for coffee. Tea, kapok, sisal, cinchona, and kueme nuts were being investigated for this purpose with varying degrees of success; but with the condition of the world's markets even as late as November of 1935 the prospects of these crops with the exception of sisal were not very promising.

Sisal, which during our stay in Tanganyika seemed to be enjoying its first prosperous season in many years, owes its success in part at least to the efforts of Amani. A new variety, hardier and more rapidly growing than the parent stock, had been developed in Amani from a sport and was being rapidly spread in most plantations. We were shown the original plot of the new variety in Amani and were struck by its apparent superiority. It is distinctly purplish, in contrast to the pure green of the mother stock, and is called *Agave amaniensis.*

Sugar held but a minor position among the varied interests of the Amani scientists; but we were shown a fair sized plot in which were growing, carefully tended, several varieties of recent introduction mostly I think from India. In connection with our visit to this plot, we were told that no large sugar cane plantation existed anywhere in Tanganyika, but that a newly founded concern either planned or had already begun the erection of a large mill. Rumor had it that this mill was to be brought from Java, having belonged to one of the Javanese concerns which did not weather the late depression; but my further travels in Africa led me away from Tanganyika before I could ascertain further developments of this ambitious project.



The native forest at Amani. (Photograph by N. H. Krauss.)

Our attention was drawn in Amani by the great abundance of introduced trees and plants; and the size of many of them brought to our minds the reminder that much, if not most, of what is now found in the Station owes its presence there to the original German founders of the institution rather than to the present English occupants. This thought struck me particularly on visiting a beautiful wooded nook referred to occasionally as "Zimmerman's Corner," where a great number of Aroids still remain to witness the interest which the last German Director of Amani took in the introduction of new varieties.

Strikingly conspicuous among introduced trees were a number of conifers. Rearing their spiky heads incongruously above a tangled mass of luxuriant tropical vegetation, these were said to have been planted by early German arrivals during a violent fit of nostalgia. But no similar reason could be attributed to the introduction of many other trees, among which I noticed very fine specimens of *Ficus nitida* and a goodly sized planting of Cedrelas of various species which, judging by their size, may have been some forty years old.

Not on the grounds of the Station but in an adjacent estate called "Nderema," I was greatly surprised to find camphor trees growing wild. I believe they were the regular Japanese camphor *(Cinnamomum camphora)* of commerce, and I was told that from a small plot planted by early immigrants they had now spread over, and thickly covered, a total area of some 200 acres. There was some talk of developing the industry in a small way, but I have heard of no further developments.

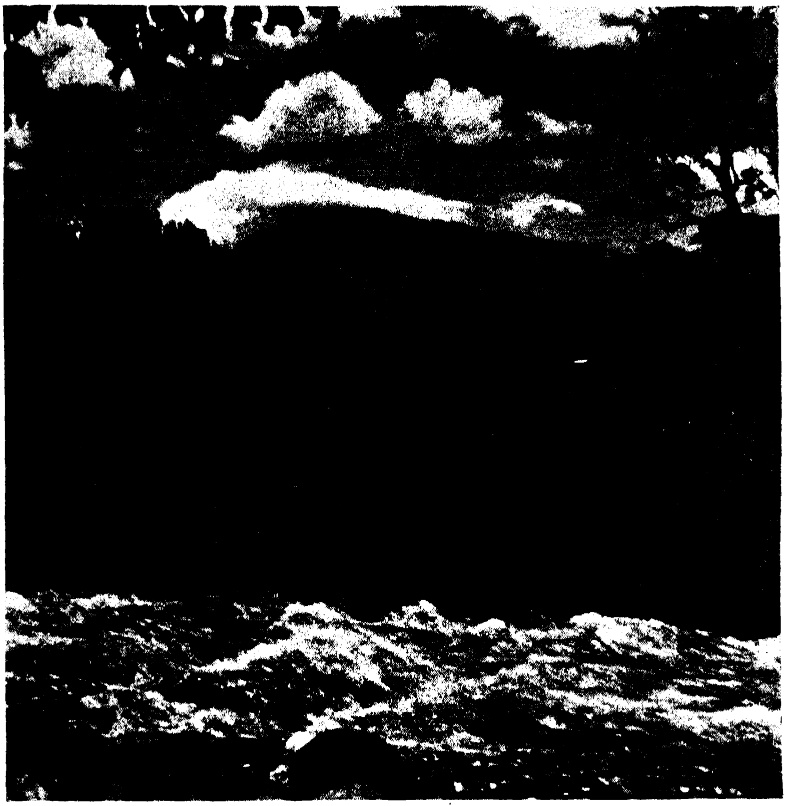
The fauna of Amani is, of course, very different from that of the Amani plains and the difference is characterized at once by the great abundance in Amani of the fantastic hornbill, *Bycanistes cristatus,* a large black and white bird with a strong, orange-colored beak almost the size of the bird's body. This enormous beak serves in the emission of sounds of nerve-racking raucousness and in the destruction of large quantities of forest fruits.

A large and handsome Colobus monkey with white markings on the face, back, and tail was easily found; and other animals, including several varieties of monkeys, duikers, bushbucks, and wild pigs were not scarce, but finding them was a matter of chance.

Snakes were considered plentiful by the natives; but the staff of the Station could report only one case of snake bite in many years and that not a fatal one.

Some 350 miles inland, east and slightly north from Tanga, the map of Africa shows two large volcanoes, Mt. Meru and Mt. Kilimanjaro, approximately 15,000 and 20,000 feet high respectively. Rising from the vast elevated plateau which extending south from Abyssinia is bounded on the west by the East African Rift Valley and constitutes the backbone of Tanganyika, these two volcanoes cradle on their southern slopes one of the rich coffee-growing areas of the world, and perhaps the most picturesque town in the Territory. In this town, Arusha, I spent late March and early April and, during a second short visit, the first days of June.

As the study of the fruit flies affecting coffee was my main concern in this region, I had occasion to see quite a bit of the industry and to learn something of the problems which it faces. The poor market then prevailing was, of course, the basic difficulty. Shortage of labor, however, was the handicap of which the planters most bitterly complained. Their product some of them explained enjoys preference



Scene near Arusha, Tanganyika. Mt. Meru in the background.

and is less affected by poor market conditions than other coffees, but even so, should the labor situation continue on the present trend, the day is not far distant when this region will not be able to supply even its limited share of the world's demand.

The method of working or "curing" coffee in Arusha is in some slight but important respects different than that followed elsewhere. Because flowering and ripening occur continuously during the fruiting season rather than at more or less definite intervals as often happens in other places, harvesting is necessarily a continuous activity which is carried on with unremitting intensity during the whole season. Harvesting is also, by choice, more selective than in other countries so that only fully ripe berries reach the mill. The milling process is, therefore, much simpler and less expensive in Arusha. The complicated system of flumes and settling tanks required in other places to separate and treat the berries according to their varying degrees of ripeness is reduced to a single tank where unsound berries, being lighter, float above the sound ones and are easily decanted. In some cases I was told even this process is eliminated and the coffee is carried directly from the field to the pulpers.

The vast drying platforms of concrete, on which in Central and South America coffee is daily spread out in the sun and raked over, are non-existent in Arusha. Their place is taken by large screen-bottomed trays, which, although requiring a considerable amount of handling, are said to result in a saving of time and labor.

Warriors of the Warusha tribe, allied to the Masai, Arusha.

The roads of Tanganyika are not always passable during the rainy season. On the road to Ngorongoro Crater.

In the field of Entomology my attention was repeatedly drawn to the damage by two pests which seemed particularly to worry the planters. One of these, the *Antestia sp.* to which I have already referred in connection with my visit to the Amani Experimental Station, seemed fairly well checked on the more progressive plantations through the methodical application of stomach poison sprays. The other, however, a Cerambycid of the genus Anthores, presented a problem for which no solution was yet in sight. Endemic on many hosts native in the region and with a life cycle of only one year, this insect is practically beyond eradication from the bush that everywhere encroaches upon the cultivated areas of Arusha. An inexhaustible supply exists, therefore, for the reinfestation of cleared areas, and it is exceedingly difficult and expensive to clear these in the first place. In coffee trees, insertion of paradichlorobenzene crystals into the tunnels of the larvae has been tried with only partial success, and so far no more efficient method of control has been devised than to have men pull the larvae out by means of a thin wire bent into a small hook.

In many "Shambas," as plantations are called in Tanganyika, a considerable proportion of the coffee trees were apparently suffering from a disease which had not been diagnosed and was causing great concern. Appearing first as a general discoloration of the foliage, every indication of the trouble sometimes disappeared within a few days, without further injury to the tree; but in most cases discoloration was quickly followed by complete wilting and prompt death of the whole plant. As practically no work had been done on this disease by the agricultural authorities of the region, and evidently none whatsoever by the planters themselves, it is quite possible that the damage observed was not due to a disease at all, strictly speaking, but to some other unsuspected agency. My suggestion that this agency might be the enormous population of scarab grubs found everywhere in the vicinity of Arusha was received with favor by several planters, and one in particular made efforts to secure a supply of white arsenic to apply to his fields. What success he had, if any, I have not heard, but having lately read an account of an attack on coffee in Java by larvae of Lachnosterna I am further inclined to believe that white grubs may have been the cause of the trouble in Arusha.*

Though situated in a zone extensively cultivated, Arusha lies within easy distance of vast plains where many of the larger African animals are still plentiful. In the course of fruit fly work and during walks or automobile rides which I took specifically for the purpose, I was able to approach closely and in some cases to photograph herds of zebra and giraffe and large flocks of ostriches. On two occasions I hunted lion; but although the beasts came near to our camp during the night and were plainly heard, I was unable to find them after the break of day. Failing to shoot lion, however, I was amply compensated during these two hunts by the sight of many jackals, hyenas, and literally hundreds of antelopes of many species, to say nothing of numerous minor animals and birds.

During one trip, longer than the others, I visited the famous Ngorongoro Crater about 100 miles west of Arusha. Some 15 miles in diameter and 2,000 feet below

* de Fluiter—A preliminary communication regarding an investigation on an attack on coffee in Java by larvae of Lachnosterna, Review of Applied Entomology (Series A) Vol. 24, page 627, 1936.

the rim, the floor of this extinct crater is sometimes overcrowded with game of every species, as many as 50,000 gnus and zebras having been seen there at one time apart from smaller game; but during my visit no animals of any kind were in evidence. Dozens of hyenas and jackals, hundreds of antelopes which we saw on our way to the crater, and the one old rhinoceros bull which crossed the road fifty yards ahead of us, did not constitute in the opinion of my guide sufficient justification for the trip. It all lies in the point of view.

Zanzibar

Forced by the collapse of the A.A.A. and subsequent financial difficulties of the Department of Agriculture to remain much longer in Tanga than we originally intended, Mr. Krauss and I created interludes in our protracted stay by making short visits to the island of Zanzibar which lies only about 100 miles southwest of Tanga. Flying across, I remained on the island from December 3 to December 13, and was lucky to hit one of the drier periods of the year, as most of its sixty inches of rain supposedly falls during April and May. There were more or less light showers,

A typical street scene in the city of Zanzibar.

nevertheless, every day that I was there and the temperature and humidity seemed to be very much more disagreeable than they are in our own Hawaii during the hotter months.

An independent Sultanate before 1890, Zanzibar is now to all intents and purposes an English colonial possession. A Sultan still keeps his palaces and his motor cars; but his power gone, he has become only a voice in an Executive Council whose important member is really a British resident. The atmosphere of the old days remains, however, and wandering through cool labyrinths of narrow streets, amid turbaned and burnozed figures, with the muezzin call ringing in his ears, the visitor to Zanzibar may still feel closer to the past glories of the dead Arabian Empire than to the present day Africa. The population is not, nor has it ever been, predominantly Arab, but Swahili, and these natives of Zanzibar, however greatly the course of the centuries may have mixed their blood and changed their customs, are obviously rooted in the negroid strains of Africa. Their language enriched and modified by the Arabs, Portuguese, and other conquerors is today the lingua franca of Kenya, Tanganyika, and parts of Uganda. As it is spoken in Zanzibar, the liquid quality of its tones and the ease with which it can be learned constitute one of the pleasant features of the place.

The total population of the Sultanate, which includes also the Island of Pemba, very seldom visited by the casual traveler, numbers some 203,000 inhabitants, and of these the East Indian contingent, with some 14,000 members, is probably the most important racial group. Harder working than the Arabs and distinctly more able in the handling of money, the Hindus have gradually acquired much of the land and since the war are rapidly gaining control even of banking and the larger part of import and export business. The house of Karimjee-Ivanjee, landholders, wholesale exporters and importers of every kind of merchandise, is the best known business concern in Zanzibar and one of the most powerful in all of East Africa as well.

Agriculturally Zanzibar is so exclusively committed to the production of cloves and copra that but little land is left for the raising of other products. A wide variety of fruits and vegetables is grown in small plots and family gardens and evidently suffices to fill the local demand, but of the major staples everything is imported. Not even sugar or rice are now produced, although 100 years ago the former was an important item of the export trade.

The article of commerce which is known as cloves is produced outside of Zanzibar only in Sumatra, Penang, Malacca, and Madagascar; nowhere in quantity comparable to the production of Zanzibar. It consists of the dried flower buds of a tree, *Eugenia aromatica* of the Myrtaceae, the family of the well known Eucalypti. Thirty or forty feet in height, of elongate rather than spreading habit and with a great abundance of small, shiny, sweetly scented leaves, clove trees make plantations which rival in beauty the finest of gardens. Every bit as delicate, unfortunately, as its beauty might lead one to believe, the tree demands for satisfactory growth and production the deep, rich soil of the higher areas of the island, and it is only found there. Even there, under optimum available conditions, it exhibits a high degree of capriciousness and shows extraordinarily large variations of yearly output which have not yet been satisfactorily explained. The average annual yield for one tree

The clove crop of a small producer is dried by the sun on mats laid out in his backyard, Zanzibar. (Photograph by N. H. Krauss.)

is said to be around 4 or 5 pounds of the dried buds, but it may rise to 10 or 12 or fall to nothing without visible cause. As the industry has only recently come under the supervision of trained European agriculturists it is hoped that in the near future this peculiarity will be explained and perhaps avoided.

It is an interesting fact that the maximum age that can be attained by *Eugenia aromatica* is not known, nor the age at which a tree is most productive. No records were ever kept by the original Arab planters of Zanzibar that might today cast light upon these points, nor is it even known with certainty when nor whence the clove tree was originally introduced, although it is said to have been brought from Mauritius in the beginning of last century.

The harvest season of cloves lasts from July to February. In the days of the Arab domination it employed resident slaves, but today it depends on seasonal migration of labor from the mainland and often runs into the snag of labor shortage. With the steady rise of employment in the sisal and other industries of the mainland, it is feared that this snag will appear more and more often.

Picking of the buds is done by hand and foot, so to speak, for pickers climb directly on the trees without the aid of ladders or paraphernalia of any sort. The process requires considerable skill and agility, and it depends on the goodwill and carefulness of each picker to gather the buds at precisely that stage in their development when they have reached their full growth but have not yet started to open up into flower. This degree of maturity is discernible to the initiate through delicate color variations of the buds and produces the best and most expensive cloves which are used exclusively in the spice market. Immature, overdeveloped, or broken buds are only used in the distillation of essential oils and have to be separated from the perfect cloves by hand, a very laborious process which commences at the time of

picking and is only finished after the cloves have been spread out on mats and dried in the sun.

The process of drying in the sun, incidentally, is all that cloves undergo in Zanzibar, for distilleries, with the exception of one which had not been completed at the time of my visit, have never existed on the island. Distilling has always been done in England or India.

Although in 1872 all the clove trees on the island of Zanzibar were destroyed by a hurricane which freakishly missed the sister island of Pemba, all the plantations antedate by far the era of British influence. The industry, therefore, owes as yet but little to the modern science of agriculture, but rapid strides are being made by the Department of Agriculture in the scientific solution of its many problems and it is hoped that risks to the industry will eventually be reduced and its yields greatly increased.

In one of the series of experiments of the Department which particularly interested me, an endeavor was being made to determine the best leguminous cover crop for clove plantations, and three plants seemed to be giving promising results. These were *Calopogonium muscinoides, Tephrosia candida* (the Hawaiian *ahuhu*), and a species of Centrosema, all of which had been imported for the tests.

Although the clove industry of Zanzibar was more or less able to hold its own through the thick and thin of the late world depression, that was not the case with copra. In consequence of the depression, a large proportion of the palm lands is in the hands of the government to whom it accrued in lieu of defaulted taxes. Much against its wishes, therefore, the Department of Agriculture is actually in business and is forced to dedicate as much time to the commercial as to the scientific aspects of copra production. The government, I was told, was anxious to end this state of affairs, but it was only gradually succeeding in returning its lands to private ownership, although they were being disposed of on terms very favorable to the purchasers.

Kenya

Although I later returned for a shorter visit than my first one, I left Arusha the first time early in April and made my way to Nairobi, the capital of Kenya.

The trip by rail takes more than 24 hours and entails a prodigious amount of waiting and transferring at different stations. By car, however, it either takes eight hours if the road is dry, or it cannot be done at all when the road is wet. It was dry, fortunately, early in April, and my memories of the trip are pleasant. Traversing for about 200 miles an almost completely uninhabited plateau, the road leads one through rolling plains which in their physical features and in their enormous abundance of game recall our own western prairies in the days of the bison and the redskin. In Kenya, however, the grass is always green, and the variety of animals is incomparably greater than it ever was in America. Development of the ability to distinguish all the species would probably require many more weeks of close association with the "veldt" than fell to my lot, but the species I was able to recognize included by their common names, giraffe, eland, zebra, congoni, wildebeest, Grant's gazelle, Thompson's gazelle, duickerbuck, and bushbuck. Grant's and Thompson's gazelles seemed to be most abundant and could be seen almost any where along the road, singly, in couples, or in herds of hundreds. Very curiously,

most of these animals exhibit but slight alarm at the approach of an automobile, but a man on foot must spend hours in careful stalking to get near enough for a good photograph.

The grass cover of these plains is composed mainly of Rhodes grass, *Cloris gayana,* which harbors an enormous quantity of insects. Vicious ticks, grasshoppers of several species, and a small purplish Cantharid were most numerous and, if the car left the road even for a few yards, they collected on the radiator by the hundreds.

Not among the larger animals in the more open areas but in widely scattered thickets of small trees and bush, these plains are also thickly populated by a very desirable avian fauna. I learned to distinguish among the very numerous constituents of this a number of species including a very tasty francolin and two species of Guinea fowl, and on one occasion I found one species of the latter so abundant that a flock occupied the road for a hundred yards ahead of my car. By slightly increasing my rate of speed on that occasion I could have supplied succulent dinners to all the inhabitants of a fair sized town but, choosing instead to do some investigation, I discovered that African birds like African mammals will flee with alacrity the minute a man descends from his car.

In Nairobi, Kenya, where Mr. Krauss made his headquarters for more than two months, I spent little more than one week. With a population of some fifty thousand inhabitants of which about six thousand are Europeans, this is a fair sized town and a center of commercial importance to its own colony, to Tanganyika, and to Uganda. It is not in any sense a beautiful town, but as a large and typically African conglomeration of primitive and civilized features it is quite interesting. Its hotels, the number of which seems disproportionate to the size of the place until one recalls Nairobi's rank as a tourist center, are comparable to the good ones of Europe. The same can almost be said of the many well-stocked stores, and more perhaps, of the impressive vegetable market where, housed in a building modern in every detail, the fruits and vegetables of almost every clime can be obtained at standard prices.

Although rather poorly located in a treeless plain and regularly subjected earlier in its history to strong, dust-laden winds, Nairobi has to a great extent overcome that handicap by the wholesale planting of native and introduced trees. Because of their greater size, the usual Grevilleas, Ficus, Eucalyptus, and palms are the most conspicuous among these, but there are also many others including berry and fruit-bearing varieties so abundant as to make Nairobi one of the most favorable locations for our fruit fly work. One species of Strychnos, the Nux-vomica tree, was particularly well spread throughout the city and provided Mr. Krauss with a large part of his fly rearing material. The fruit of this tree is a small, yellow colored drupe and in many parks and public lots the ground was thickly carpeted with it.

The Coryndon Memorial Museum, a few blocks from the center of town, is well worth a visit. Founded by the Society of Natural History, and supported by it with only meager aid from the Colonial Government, this institution does honor to the enthusiasm and ability of its small and poorly rewarded staff.

Uganda

My travels in the Crown Colony of Uganda began with a short stay in the pleasant town of Kampala. Important as the largest commercial center of the colony, this town was to me chiefly interesting because of its population which consists predominantly of members of the Buganda tribe. Reputed to be the most advanced of the native peoples of Africa, this tribe constitutes a semi-rural community of idyllic charm; and nothing gave me more pleasure during the week that I spent in Kampala, or perhaps in all my African travels, than long evening walks which took me into the heart of their thickly populated districts. The happy laughter characteristic of the Negro rings there against a background of order, cleanliness, and comfort which is not remotely approached in any of the other African countries I visited. The people, protected in their tenancy by a wise government, own most of the land and live off it with relatively small effort. Most of them cultivate cotton, peanuts, or other readily marketable crops in addition to the cassava, millet and vegetables for their own staple consumption. They all own goats; a few own cattle; and, more perhaps as an index to social standing than because of comfort or necessity, practically every household boasts the possession of one or more bicycles. Their homes are invariably clean, near to the city often provided with electricity and running water, and in every instance surrounded by gardens the upkeep and appearance of which impress the visitor as objects of family rivalry. In the matter of clothing, individuals are still too often given to the fanciful combination of totally unrelated and sometimes ludicrously contrasting pieces of apparel, but on the whole everyone dresses becomingly in simple and light clothes of European pattern. The women, more distinctive than the men, dress in very bright colors and usually wear four or five skirts superimposed upon each other, with a fold of the material gathered in back into a sort of crinoline that in no way reduces the already respectable girth of the wearers.

There is still left to the Buganda a native king with a considerable measure of influence on the local affairs of the community. He is known by the title of "Kabaka" and he and his palace which crowns one of the numerous hillocks over which Kampala spreads are objects of almost pathetic reverence on the part of the natives.

After Kampala I spent a few days in Jinja where, in a country of similar physical features but entirely different population, my interest reverted to the flora and the wild life of the place.

Housed in a hotel removed little more than a stone's throw from Lake Victoria and the famous Rippon Falls, I made my first acquaintance with crocodiles and hippopotami and spent several pleasant evening hours observing the activities of the latter. Hidden from view during the warmer hours of the day in the deeper central portion of the lake, dozens of these animals make their appearance late in the afternoon near the shore. There, gamboling and cavorting in the water in a manner much like that of happy children in a swimming hole, they remain until dark, and later under the cover of night, they walk out on the land and often spend many hours wandering about. How far they wander I was not able to ascertain conclusively; but it was sworn to me that people had often met them in the streets of Jinja, and that it was a usual experience to find them roaming over a golf course

This man-powered ferry serves as a cheap and convenient way of crossing the Nile river in the West Nile District of the Northern Province, Uganda.

A rest camp in the West Nile District, Northern Province, Uganda.

which lies some 300 yards from the lake. Spending a good part of a clear night in this golf course, I myself did not meet any of the hippos therein, but I saw unmistakable traces of their recent presence and observed the deeply worn paths which they have traced in years of nightly visits. It was astounding that in one place these paths rose at angles of 60 or 70 per cent over a 200-foot cliff; and I considered myself cheated by chance in not being able to witness the hippopotami actually surmounting this obstacle. With their enormous weight and very short legs, it is surprising that they can climb at all, and it must be a memorable sight to see them scampering up grades of steepness that would tax even a man's ability.

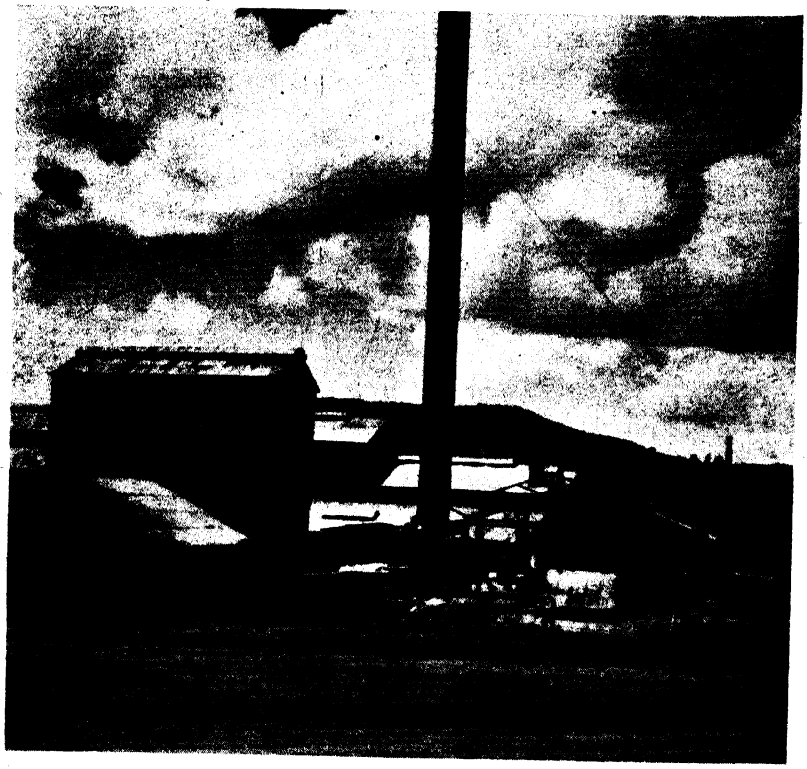
Some of them came within twenty feet of me in the lake without seeming to take much notice of my presence, but I was told that under certain circumstances hippos will attack man, and that a light suddenly directed at them in the dark is one of the few things that will anger them. Sometime before, a visitor ignorant of this idosyncracy had been trampled to death in the yard of the hotel where I stayed. On learning this, needless to state, my own nocturnal explorations of Jinja were carried out without benefit of lights of any sort except the silvery radiance of helpful Luna.

The shores of Lake Victoria cannot be considered ideal home sites, among other reasons, because of the occasional appearance of enormous swarms of bothersome insects. While having my first dinner in the hotel I was witness and victim of one of these invasions which consisted of veritable clouds of very minute Chironomidae with a very distinct liking for tomato soup. Trying to trace their origin to the lake next morning, I failed to discover it, but found instead that some areas of the grass nearer the water and practically every bush or small tree were so thickly covered with the exuvia of another insect, an Ephemerid or May fly, that the leaves looked gray. On the under surface alone of one small leaf I counted 43 exuvia.

Near to Jinja, some 15 miles along the road to Kampala, I visited the only large plantation of sugar cane that I saw in Africa. Commonly known as "Lugazi," its official name is "The Uganda Sugar Company." It is owned by an East Indian financier. The majority of the employees are also East Indians, but of course there was also a Scotchman, and he, the Chief Engineer, filled me with tea and buns and between drinks showed me around his domain. The mill, of German make with 2 crushers and 12 rollers, has a daily capacity of 700 tons of cane and produces 14,000 tons of plantation white sugar per annum, most of which is consumed in Uganda itself. The total area of the plantation, most of it under cane, is around 7,000 acres; and the preferred cane variety is POJ 2878 with 2725 close behind. The cane appeared perfectly clean in so far as insect pests were concerned, and no one on the plantation was able to produce for my collection even a single specimen of the moth borer which is the only cane pest known in the region.

From Jinja, by a little known though important artery of commerce, the back road so to speak into the Belgian Congo, I journeyed eastward to Busingiro Forest. Employing a poor train from Jinja to Lake Kyoga, a paddle steamer across the lake, and an automobile from the lake to my final destination, the trip was neither rapid nor very comfortable, but I found full compensation for my troubles in the great beauty and interest of the route and its objective.

Situated between Lakes Kyoga and Albert, Busingiro Forest covers some 350 square miles and consists of several more or less adjacent but separate portions, of



The Uganda Sugar Company, fifteen miles from Jinja, Uganda.

Saw mill in Busingiro Forest, privately run under government control.

which one, Budongo Forest, is by far the largest and most interesting. On the very edge of this enormous mass of trees as the guest of W. J. Eggling, Assistant Conservator of forests, I lived in a house of size and comfort which I was far from expecting in that remote locality. Built on the slope of a steep hill, this residence commands a magnificent view quite reminiscent of our own Great Lakes District as we find it described in the tales of Fenimore Cooper. As one sat in the glow of late evening sipping the inevitable afternoon tea of every British household, with Lake Albert stretching all silvery on one hand, and on the other Budongo Forest an uninterrupted mass of trees fifteen miles long, it was not difficult to imagine that the last rays of the sun flickered and glimmered from the lances and tomahawks of Indians impatiently waiting behind trees for the darkness so propitious for their unpleasant habits. But of course there were no redmen in Budongo; nor were there likely to be any furtive black ones behind the trees, for this country is not heavily populated and the few negroes who go out after dark do so in noisy groups that stick to the widest and clearest openings they can find. Wild animals are still numerous enough even along the fringe of cultivation that borders the forest to make solitary night errands unsafe, particularly to natives too poor to travel in motor cars and by law prevented from possessing fire arms. A leopard had been killed not long before my stay on the very porch from which for three weeks I watched the sun set, and lions were of common occurrence on the road that ran a quarter of a mile below.

There are no pygmy people nor pygmy elephants in Budongo Forest such as are found in Ituri and other forests of West Africa, nor are the elephants of Budongo, strictly speaking, denizens of the forest. Their tracks can be found far into the forest, as I often did, but they indicate only the incursions of small detachments from large herds which make their permanent home in the basin of Lake Albert. Kindly invited by Mr. Eggling to take part in a hunt in this basin some 20 miles from Budongo, I observed the age-old paths which the elephants' migrations have worn on the face of the eastern escarpment. We failed actually to meet elephants on this occasion, however, and my first contact with them did not occur until a much later date in the West Nile District.

As might be surmised from its geographical location, the flora of Busingiro shows affinities both to the eastern and the western floras of Africa; and there are those who think it may represent a central remnant of a wide and continuous belt of forest once spanning the continent from coast to coast. If it ever existed, this belt has completely disappeared in most places due to climatic and physiographical changes; and the same fate is said to be evidently in store for Busingiro, which from an original tropical rain forest is slowly changing into a drier type with a consequent reduction of the species and individuals now found among its components. The Government of Uganda, I was glad to learn, is doing everything possible to retard this inevitable reduction, and if it ever reaches a stage of complete consummation it will be only in a small degree due directly to the activities of man which in this area are carefully regulated.

Among the innumerable species of plants which are found in the flora of Busingiro, of which even some of the common fringe-of-the-forest varieties are yet unknown to science, there are many timber trees of great value. Perhaps *Khaya*

Busingiro Forest Station, Uganda.

Communal granaries, West Nile District, Northern Province, Uganda.

anthotheca, the African mahogany, is the most important of these, but *Chlorophora excelsa* (Mvule), *Parinarium excelsum, Podocarpus gracilior,* and a very abundant species of Maesopsis also have a market demand. In one small mill which is privately run under the close supervision of the forestry authorities of Busingiro I saw fine logs of some of these trees destined, as I was informed, for the hammers and nails of Jinja, Kampala, and points even farther east.

After Busingiro, still as a guest of Mr. Eggling, I crossed Lake Albert and sailed down the Blue Nile in a comfortable little steamer to a spot on the map of the West Nile District called Pakwach. Thence, traveling in the front seat of Mr. Eggling's light delivery truck between Mr. Eggling and his cook, and most of the time holding his terrier on my lap, I traversed the whole length of the West Nile District to another spot called Soroti, where I regretfully left my genial companions and boarded the prosaic wood-burning train which overnight returned me to Nairobi.

Of course adventures continued to pile up in my diary during this latter part of my trip, but as they included for the most part experiences of personal interest only, such as a bout of malaria, a close escape from a white rhinoceros, and a pugilistic encounter with a tipsy station guard, I shall not record them here.

Soil and Plant Material Analyses by Rapid Chemical Methods—II

By Francis E. Hance

CONTENTS

Foreword

It was stated in the previous article "Rapid Chemical Methods" (R.C.M.) (2), prepared for publication in the summer of 1936, that research was in progress at that time, the purpose of which was to develop entirely new chemically stable, fast-to-light, inorganic color standards for use in colorimetric R.C.M. analyses. This work, which was undertaken by Q. H. Yuen, E. K. Hamamura, T. Nishimura, F. Fong and the author, is now complete. Discussion and details, with formulae, appear later in this publication.

As Hawaiian plantation agriculturists and Experiment Station workers extended their fields of study of soil, plant material, irrigation water, and factory by-products, it became necessary, from time to time, to augment existing R.C.M. procedures with supplementary assemblies having similar, yet equally efficacious, rapid analytical characteristics. Full details of all the newer R.C.M. analyses appear later in these pages.

Another subject to be discussed pertains to the marked advancements which have been made in remodeling and equipping plantation laboratories.

(Note: The greater portion of discussion and data appearing under "Color Standards" refers to a previously published manuscript describing various R.C.M. procedures.)

Color Standards

Equipment:

A number of excellent soil-testing kits are available today which are equipped with ingenious and practical devices for comparing colors of unknown solutions with standard color discs or plates. These are arranged together progressively by hue or shade in the longitudinal plane of the adjacently placed vial of test solution. The materials comprising the standard colors are, in most cases, durable and non-fading. Usually the entire color comparison assembly occupies but little space. Frequently it is a product of careful design and manufacturing skill. Nevertheless, these comparators are, in our opinion, not entirely satisfactory for R.C.M. laboratory usage, although they are unquestionably adequate for conventional "field" or "kit" analytical estimations.

The color comparison devices used in R.C.M. work are not portable. On the contrary, their position in the laboratory is a fixed one and a screen or hood is usually provided which gives the operator protection from all sources of extraneous light. R.C.M. "illuminators," as we term them, are equipped with calibrated electric light bulbs and snap switches for control of illumination. Examinations of test solutions by comparison with standard color solutions are made in a sliding rack, the latter moving back and forth on apparatus (painted dull [flat] black) before a source of illumination which is mellowed by an opal glass window diffusing softened light. The color standards are liquid solutions sealed into vials identical with those used in the tests. These standards are placed along the rack in colorimetric sequence. Notched recesses are provided between the standard vials for inserting the test solution vial in making a color reading. Other details concerning the "illuminators" may be found in the previous article on R.C.M. A full vial-length comparison between the color developed in the test solution and the two nearest "matches" of colored standards may be made before the illuminated field. This feature simplifies the matching performance and, we have found, adds to the precision of the determination.

The Color Standard Solutions:

We have found that, unfortunately, supposedly non-fading aniline dyes deteriorate quite rapidly when dissolved in ordinary solvents and when subjected alternately to the unavoidable warming and cooling in glass containers used as "standard" vials for R.C.M. colorimetric analyses.

The fugitive nature of such standards, the resulting uncertainty of their dependability *as* standards and the expense and labor involved in replacing them at frequent intervals led to an intensive experimental study in the development of colored solutions having greater durability and permanence. Colors of solutions of individual inorganic salts are, in many cases, both fast to light and permanently stable chemically under certain environmental conditions. However, the character of solvents, the changing temperatures to which the standards are subjected and the effects produced by chemical reactions when mixtures of two or more of these basic or primary colored solutions are brought together are factors which limit the possibilities of a development of this character. Phosphate blues, for instance, which are required in a large number of gradations in shade and hue, cannot successfully be produced from aqueous or ammoniacal solutions of copper salts in any of the many combinations which were studied. Similarly, aqueous solutions of cobalt salts, which are pink in color, were equally out of the picture. But combinations of strongly acid (7 parts hydrochloric acid to 3 parts distilled water) solutions of cobalt and copper chlorides produced a range of color effects in blue which completely covered the entire field of requirements for all classes of phosphate determinations at laboratory temperatures between 71° F. and 100° F. (25° C. and 41° C.). (This range of temperatures approximately embraces both extremes of cold and warmth which may prevail in laboratory buildings in the Territory of Hawaii, U.S.A.) Modifications of the formulae presented below may be made to meet different temperature ranges in other localities.

Preparation of Inorganic Color Standards for Phosphate Determination by R.C.M.:

In soils having comparatively low concentrations of phosphate it frequently happens that, during the digestion of the soil with the solvent, colored extractive matter is carried into solution. This colored impurity may not be entirely eliminated in the process of analysis. In a majority of cases, however, this *undesirable* feature is not encountered. Therefore, we usually obtain a colorless soil extract, or less commonly, one having a yellowish tinge. In the latter case the development of the phosphate blue must be made in this pale yellow medium and since the intensity of the developed blue is low (in low-phosphate soils) the resultant color in the test solution is of a distinctive greenish-blue hue. To meet this contingency a separate set of appropriately shaded color standards has been produced.

In the former case, where colorless soil extracts are obtained, normal phosphomolybdate blue colors are developed in the course of the analysis. A set of standards is provided for these normal determinations.

Furthermore, analyses of generally low-phosphate soils occasionally show such low concentrations of "available" (readily soluble) nutrient that very little coloration, or practically none, is produced in the final test solution. In such cases the result is reported as "low," comparison having been made with the color standard adjusted to match the natural color of the soil extract. In the R.C.M. scheme of

phosphate-standard classification, the letter "X" is used to denote the series of standards which have been prepared for use in the analysis of colorless soil extracts and the letter "Y" to denote the series of standards for use with extracts having a yellowish tinge.

To Prepare the R.C.M. Color Standards:

Solution A:	15 gm. cobaltous chloride ($CoCl_2.6H_2O$) per 100 ml. 7/10 HCl.
Solution B:	5 gm. cupric chloride ($CuCl_2.2H_2O$) per 100 ml. 7/10 HCl.
Solution C:	1 ml. Solution "B" diluted to 25 ml. with 7/10 HCl.
7/10 HCl:	7 volumes of concentrated HCl (12 normal) diluted with 3 volumes of distilled water.
$CoCl_2.6H_2O$:	Baker's C.P.
$CuCl_2.2H_2O$:	Merck's Reagent Grade.
Conc. HCl:	Any C.P. grade.
Solution I:	5 gm. potassium dichromate ($K_2Cr_2O_7$) per 500 ml. distilled water. Filter before making up to the mark.
Solution II:	50 gm. cobaltous sulfate ($CoSO_4.7H_2O$) per 500 ml. distilled water. Filter before making up to the mark.
$K_2Cr_2O_7$:	C.P.
$CoSO_4.7H_2O$:	C.P.

Soil and Cane Juice Phosphate Color Standards:

Series X, Soil Phosphate

(For use in matching colors developed in water-white soil extracts.)

Standard	ml. solution required				Approximate total volume
	Sol'n A	7/10 HCl	Sol'n C	Distilled water	
Low	...	100.0	...	...	±100 ml.
Doubtful	9.5	65.0	1.8	23.7	±100 ml.
Medium	13.6	61.2	3.4	21.8	±100 ml.
High	15.9	61.0	6.1	17.0	±100 ml.

Deliver each solution, the HCl and the distilled water from individual calibrated burettes to a common container. The relative amounts of 7/10 HCl and water are very critical as far as the proper shade of color is concerned.

Series Y, Soil Phosphate

(For use in matching colors developed in soil extracts having a yellowish tinge.)

Standard	ml. solution required						Approximate total volume
	Sol'n I	Sol'n II	Sol'n A	7/10 HCl	Sol'n C	Distilled water	
Low	2.5	5.0	...	...	...	242.5	±250 ml.
Doubtful	...	...	9.2	63.2	4.6	23.0	±100 ml.
Medium	...	...	13.2	59.2	7.9	19.7	±100 ml.
High	...	...	15.5	59.5	9.5	15.5	±100 ml.

Proceed as directed under Series X, soil phosphate color standards, observing the same precautions regarding the relative amounts of 7/10 HCl and water.

High-Register, Soil Phosphate

(For use in matching colors developed in soil extracts, the latter containing amounts of readily soluble phosphates in excess of the highest concentrations encountered in the X and Y Series.)

Standard	Sol'n A	7/10 HCl	Sol'n C	Distilled water	Approximate total volume
	ml. solution required				
H.R. I	16.0	62.0	11.0	11.0	±100 ml.
H.R. II	21.9	54.6	13.7	9.8	±100 ml.
H.R. III	27.5	45.9	17.4	9.2	±100 ml.
H.R. IV	32.8	38.6	20.1	8.5	±100 ml.
H.R. V	40.1	28.7	24.1	7.1	±100 ml.
H.R. VI	44.5	22.2	26.6	6.7	±100 ml.
H.R. VII	50.8	15.4	27.7	6.1	±100 ml.

Proceed as directed under Series X, soil phosphate color standards, observing the same precautions regarding the relative amounts of 7/10 HCl and water.

Soil Phosphate Fixation

Standard	Sol'n A	7/10 HCl	Sol'n C	Distilled water	Approximate total volume
	ml. solution required				
0	44.9	32.8	22.3	...	±100 ml.
10	37.2	41.3	21.5	...	±100 ml.
20	29.9	48.3	19.4	2.4	±100 ml.
30	24.5	56.5	16.0	3.0	±100 ml.
40	18.5	62.5	12.0	7.0	±100 ml.
50	13.0	66.5	7.5	13.0	±100 ml.
60	9.7	69.4	4.2	16.7	±100 ml.
70	6.6	69.0	2.5	21.9	±100 ml.
80	4.3	70.9	0.7	24.1	±100 ml.
90	1.8	73.3	...	24.9	±100 ml.

Proceed as directed under Series X, soil phosphate color standards, observing the same precautions regarding the relative amounts of 7/10 HCl and water.

Phosphate in Juice

(Applicable to analyses of plant saps, root pressure liquids, crusher juice, etc.)

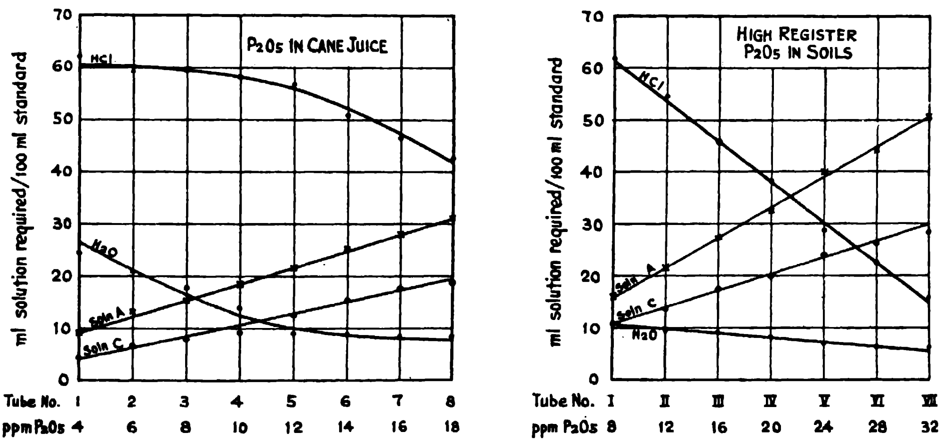
Standard	Sol'n A	7/10 HCl	Sol'n C	Distilled water	Approximate total volume
	ml. solution required				
C.J. 1	9.0	62.0	4.5	24.5	±100 ml.
C.J. 2	13.2	59.2	6.6	21.0	±100 ml.
C.J. 3	15.5	59.5	7.1	17.9	±100 ml.
C.J. 4	18.6	58.1	9.3	14.0	±100 ml.
C.J. 5	21.6	56.8	12.5	9.1	±100 ml.
C.J. 6	25.2	50.5	15.2	9.1	±100 ml.
C.J. 7	27.8	46.3	17.6	8.3	±100 ml.
C.J. 8	31.3	42.4	17.8	8.5	±100 ml.

Proceed as directed under Series X, soil phosphate color standards, observing the same precautions regarding the relative amounts of 7/10 HCl and water.

Checking Preparation of Color Standards: Graphical methods of analysis were employed in checking the proportions of component Solutions A, C, HCl, and water in the color standards of each series. For instance, in the preparation of each phosphate standard, Mr. Yuen experimented with various combinations of the 4 inorganic components until a blend was produced which matched the developed color in a phosphate solution of definite concentration. The color comparison was made visually under the same conditions as obtained in the regular rapid chemical procedure. Upon completion of a whole set of standards in this manner, the entire set was again checked colorimetrically against solutions of known phosphate concentration. Since the concentrations of phosphate represented in each of the solutions were graded to increase in a regular order, it was reasoned that were the components of each color standard plotted graphically the resulting graphs should constitute a pattern which would indicate a definite order of systematic increase or decrease for each component throughout the series. Thus, by graphical means, an additional check was provided to test the progressive regularity of increase or decrease in the components blended together from step to step in any given series of standards.

In the preparation of these graphs the tube numbers of the standards were plotted on the X-axes and the amount of each basic solution required to produce 100 ml. of the corresponding color standards was placed on the appropriate Y-axes. The plotted points then form the basis for drawing curves or line graphs for each component used. Results of these graphical analyses indicate that the prepared phosphate color standards vary systematically and apparently in a logical manner. Graphs for the high-register soil phosphate and cane juice phosphate standards are illustrated below as examples.

Graphs showing the ml. of component solutions required to produce 100 ml. of each inorganic P_2O_5 color standard in a series



Rechecking Color Standards Against Solutions of Known Phosphate Concentration:

Soil and Cane Juice Standards: Aliquots of a standard solution of phosphate (0.1 mg. P_2O_5 per ml.) dissolved in water are made up to 100 ml. in volume with Reagent 4, P_2O_5 (see Soil and Plant Material Analyses by Rapid Chemical Methods [2]). The characteristic phospho-molybdic blue color is developed in the various diluted solutions by the introduction of stannous chloride reagent as in the regular soil or cane juice procedure of analysis. In making these checking tests it is essential to bear in mind and to make allowances for:

(*a*) The somewhat darker hues in the "X" standards as contrasted with the "Y" series.

(*b*) The slightly greenish-blue coloration in the "Y" standards (as a result of the pale yellowish tinge in the soil extracts).

(*c*) The greater depth of and increased intensity of blue color in the high-register standards.

(*d*) The concentration of P_2O_5 in the test solutions for checking soil color standards. The P_2O_5 solutions used in checking color standards contain concentrations of phosphate which are less than their equivalent concentrations calculated from the percentages expressed on the respective tubes. Under the conditions of R.C.M. analysis, the color developed in the soil extract is less intense than that produced in a standard phosphate acid-molybdate solution containing an equal amount of phosphate. A series of soil extracts was made and each was divided into 2 parts. One part was analyzed for P_2O_5 by R.C.M. and the other part by a more elaborate laboratory method. The results indicated that in order to bring about an agreement between the R.C.M. and the laboratory procedures, the latter being taken as a standard method of analysis, it was found in the course of protracted study with many soil extracts that it was necessary to decrease the concentration of P_2O_5 in the checking solution to make it equivalent to a soil extract containing an amount of P_2O_5 as indicated by the R.C.M. color standards. Hence, by adjustment, the incomplete development of color in the soil extract is more accurately evaluated in the percentages assigned to the standard tubes.

There are several factors which influence the development of the phosphomolybdic blue in the soil extract. Among these may be mentioned the presence of a large amount of ferric iron; titanium also may markedly depress the blue color formation. In addition, any incomplete removal of organic matter from the soil extract will exert a similar effect. Any or all of these factors may adversely influence a normal reading.

The foregoing explanations are presented in order to make clear the apparent anomalies which may be observed in the soil phosphate data appearing below on checking procedure.

Checking Procedure, Phosphates: The color of each standard is adjusted to match the blue color developed by stannous chloride reagent in the solution of chemically pure salt of phosphate in Reagent 4, P_2O_5. The corresponding percentage of P_2O_5, as it will appear in the analytical procedure, is shown in another column.

Standard Soil Phosphate	Per cent P_2O_5 indicated in analytical procedure	ml. standard P_2O_5 sol'n (0.1 mg. P_2O_5/1.0 ml. water) to be used in making up the test solution to 100 ml. with Reagent 4, P_2O_5
X & Y Low	Less than 0.0008	0
X & Y Doubtful	Between 0.0008 and 0.0015	4.0
X & Y Medium	Between 0.0015 and 0.004	6.0
X & Y High	Greater than 0.004	8.0
H.R. I	0.004	8.0
H.R. II	0.006	12.0
H.R. III	0.008	16.0
H.R. IV	0.010	20.0
H.R. V	0.012	24.0
H.R. VI	0.014	28.0
H.R. VII	0.016	32.0

Checking the Cane Juice Color Standards: The cane juice color standards are calibrated without the necessity of recourse to any adjustments which may be needed to compensate for chemical reactions or absorptions interfering with the normal development of the molybdic blue.

Standard Cane Juice	Per cent P_2O_5 indicated in analytical procedure	ml. standard P_2O_5 solution (0.1 mg. P_2O_5/1.0 ml. water) to be used in making up the test solution to 100 ml.
C.J. 1	.004	4
C.J. 2	.006	6
C.J. 3	.008	8
C.J. 4	.010	10
C.J. 5	.012	12
C.J. 6	.014	14
C.J. 7	.016	16
C.J. 8	.018	18

Checking the Soil Phosphate Fixation Color Standards: Solutions of phosphate, having known concentrations of P_2O_5, are prepared from a C. P. phosphate salt, as indicated in the table which follows. An aliquot is taken from each, as in the regular fixation determination, and transferred to a shell vial. One ml. of ammonium molybdate reagent is then added to each vial and the color is developed by the addition of stannous chloride reagent.

Column 1	Column 2	Column 3	Column 4
Fixation Index Soil Phosphate	ml. known P_2O_5 sol'n (see text above)	Dilute sol'n of Column 2 with H_2O to total volume of:	p.p.m. P_2O_5 in diluted test sol'n (Column 3)
0	Orig. 100 p.p.m. P_2O_5	—	100.0
10	13.50 ml. of solution containing 100 p.p.m. P_2O_5	20 ml.	67.5
20	8.0 ml. of solution containing 100 p.p.m. P_2O_5	20 ml.	40.0
30	5.0 ml. of solution containing 100 p.p.m. P_2O_5	20 ml.	25.0
40	3.0 ml. of solution containing 100 p.p.m. P_2O_5	20 ml.	15.0
50	2.0 ml. of solution containing 100 p.p.m. P_2O_5	20 ml.	10.0
60	11.0 ml. of solution containing 10 p.p.m. P_2O_5	20 ml.	5.5
70	6.0 ml. of solution containing 10 p.p.m. P_2O_5	20 ml.	3.0
80	3.50 ml. of solution containing 10 p.p.m. P_2O_5	20 ml.	1.75
90	2.00 ml. of solution containing 10 p.p.m. P_2O_5	20 ml.	1.00

The Use and Care of Inorganic Phosphate Color Standards:

It has been stated previously that these standards have been calibrated to give accurate readings between the limits of 71° and 100° F. (actually 71.6° and 100.4° F.).

Anyone familiar with the chemical and physical properties of cobalt salts will understand the reasons which make such a calibration necessary. With the solutions as they have been prepared and at temperatures other than those between the stated limits, changes in hue and intensity of the various colors will occur, but the change is

a temporary one. Restoring the surroundings of the standards to temperatures within the stated limits will automatically restore the original colors.

It is not a difficult matter to calibrate the standards between limits of temperatures which may prevail indoors at localities other than Hawaii. In many cases the Hawaiian lower limit (71° F.) is not far removed from comfortable laboratory temperatures, regardless of the location. At temperatures close to the upper Hawaiian limit (100° F.), very few analysts anywhere could carry on with any degree of consistency. Therefore, it is believed that the formulae which have been presented will require little or no modification for the general worker in this field.

It is a common experience, however, even in sub-tropical Hawaii, to find the standards off-color somewhat after exposure on chilly nights in open laboratories. It may appear as questionable, but it is true, nevertheless, that changes in the color of the standards due to increases of temperature above the 100° F. limit have not been noted in Hawaii, *provided* direct exposure to sunlight has not taken place. Although it is seldom necessary to do so, the correction for restoring the standards to their normal conditions due to changes induced by exposure to abnormal temperatures is, of course, quite obvious. It is of advantage, however, to use a definite technic. The following procedure (in 4 steps) has been found quite simple and effective:

(a) Place the tubes containing the standards in a 250-ml. beaker. Add water to the level of the solution in the tubes.

(b) Remove tubes from beaker.

(c) To warm: Heat the measured water in the beaker to a temperature of about 82° F. Remove from source of heat, immerse tubes for 3 minutes, remove and wipe off excess water.

(d) To cool: Mark the level of water in the beaker, add a small amount of ice and stir until the temperature reaches about 75° F. Remove the ice and restore the original level of water in the beaker, if necessary. Immerse color standards for a few minutes, remove and wipe off excess moisture.

Precautions: The most effective and advantageous packaging of the colored standards would entail sealing the liquid contents in all-glass containers. The selection of tubes to carry these standards, tubes which are identical to those used in the analyses, preclude this desirable practice. Because of mechanical difficulties, such a glass seal, if made, will usually become shattered, due to inexpert handling and, if not to this cause, certainly to the difficulties of annealing. As a consequence rubber stoppers are used, but beforehand they are subjected to thorough and successive "cleaning" in boiling dilute alkali, dilute acid, and distilled water.

During normal use, and on standing, occasionally a few solid particles may be observed on the inner surface of the rubber stoppers, or the particles may settle to the bottom of the enclosed colored solutions. Experience so far gained indicates that this condition may be disregarded. The colors of the standards have not been found to undergo any measurable alteration in this, apparently, minor occurrence. While on the subject of rubber stoppers, it may be stated that, after the colored solution is placed in its tube and the rubber stopper has been inserted, the protruding portion of the stopper is cut off flush with the tube and the end is then sealed by dipping it into melted paraffin or colorless lacquer. Later, the sealed end of the tube is color-coded by small dots or stripes to distinguish it properly as a unit of the series to which it belongs. Small letters or numerals (or both) are placed at or near the top of the tube to designate its grade or value in its series.

New Inorganic Color Standards For Use in the Determination of Ammoniacal Nitrogen by R. C. M. (see previous article [2]):

Solution I: 5 gm. potassium dichromate ($K_2Cr_2O_7$) C. P. per 500 ml. distilled water. Dissolve the salt in a 250-ml. beaker. Filter into a volumetric flask, washing filter paper thoroughly with distilled water. Make up to mark and mix thoroughly.

Solution II: 50 gm. cobaltous sulfate ($CoSO_4.7H_2O$) C. P. per 500 ml. of solution, using distilled water. Filter before making up to the mark.

Ammoniacal Nitrogen Stds.	ml. solution required Sol'n I	Sol'n II	Make up to volume indicated below with distilled water
1	1.25	1.75	250 ml.
2	2.9	3.8	250 ml.
3	4.5	6.5	250 ml.
4	6.35	9.8	250 ml.
5	8.1	14.5	250 ml.
6	11.1	21.3	250 ml.
7	14.3	31.0	250 ml.
8	22.0	52.0	250 ml.

Deliver each solution from individual calibrated burettes to a common container, observing the precautions indicated for the preparation of the phosphate color standards.

New Inorganic Color Standards For Use in the R.C.M. Determination of Magnesia (MgO) in Irrigation or Other Waters:

The method of analysis is described elsewhere in this paper.

Solution I: 250 gm. cobaltous sulfate ($CoSO_4.7H_2O$) per 500 ml. of final solution, using distilled water. Weigh the salt, dissolve it in about 300 ml. distilled water, heat to effect solution, cool to room temperature, filter into 500-ml. volumetric flask, wash filter and make up to mark.

Solution II: 5 gm. potassium dichromate ($K_2Cr_2O_7$) per 500 ml. of final solution, using distilled water. Dissolve salt in the cold with about 300 ml. distilled water. Filter into 500-ml. volumetric flask, wash filter and make up to mark.

Solution III: Concentrated sulfuric acid (36 N) C. P. placed in 30-ml. T. K. dropping bottle.

Magnesia in Irrig. Water Standard	ml. solution required Sol'n I	Sol'n II	Sol'n III	Distilled water sufficient to make volume of
1	20.00	12.50	25 drops*	250 ml.
2	24.25	11.50	25 drops	250 ml.
3	28.50	10.50	25 drops	250 ml.
4	33.00	9.25	25 drops	250 ml.
5	37.25	8.25	25 drops	250 ml.
6	41.50	7.25	25 drops	250 ml.
7	45.75	6.00	25 drops	250 ml.
8	50.00	5.00	25 drops	250 ml.

*Exact amount required not critical.

Deliver solutions to clean volumetric flasks from burettes. Make up to mark with distilled water at temperature for which flask is calibrated.

Color Standards For Use in the R.C.M. Determination of Magnesium in Soil:

The method of analysis is described elsewhere in this contribution.

This procedure has been recently developed. For the present, color standards have been prepared for this determination from aniline dyes. Later, the more permanent inorganic colored solutions will be substituted, if that is found possible.

Solution I: 0.5 gm. Brilliant Wool Blue G. Extra dissolved in 95 per cent ethyl alcohol and made to a volume of one liter with the same solvent.

Solution II: 0.1 gm. Eryothrosine Red dissolved in 95 per cent ethyl alcohol and made to a volume of 500 ml. with the same solvent.

Solution III: 0.25 gm. Metanil Yellow brought into solution and made to a volume of one liter with 95 per cent ethyl alcohol.

Magnesium in Soil Standard	ml. solution required Sol'n I	Sol'n II	Sol'n III	95% ethyl alcohol sufficient to make volume of
1	3.625	12.125	1.875	250 ml.
2	3.625	11.25	1.875	250 ml.
3	3.625	10.00	1.875	250 ml.
4	4.00	7.50	1.875	250 ml.
5	4.75	7.50	1.875	250 ml.
6	5.25	5.50	1.875	250 ml.
7	5.25	3.75	1.875	250 ml.
8	5.50	3.00	1.875	250 ml.

Deliver solutions to clean volumetric flask from burettes. Make up to the mark with 95 per cent ethyl alcohol at temperature for which flask is calibrated.

Phosphate Color Standards From Aniline Dyes:

Independently of the development of inorganic phosphate color standards, improvements were made in the permanence and durability of equivalent standards prepared from organic dye solutions. These color standards have remained satisfactory in regular laboratory service for periods averaging about 6 months. They were prepared as follows:

Solution 2A: Dissolve 1 gm. of National Brilliant Wool Blue G. Extra in 400 ml. of 95 per cent ethyl alcohol and make up volume to 1000 ml. with distilled water.

Solution A: Dissolve 0.5 gm. of National Brilliant Wool Blue G. Extra in 400 ml. of 95 per cent ethyl alcohol and make up volume to 1000 ml. with distilled water.

Solution B: Dissolve 0.25 gm. of National Metanil Yellow, Schultz No. 134, in 400 ml. of 95 per cent ethyl alcohol and make up volume to 1000 ml. with distilled water.

Solution C: Dissolve 0.5 gm. of National Erythrosine, Schultz No. 592, in 200 ml. of 95 per cent ethyl alcohol and make up volume to 500 ml. with distilled water.

Solution D: Dissolve 0.5 gm. of National Brilliant Milling Green B, Schultz No. 503, in 400 ml. of 95 per cent ethyl alcohol and make up volume to 1000 ml. with distilled water.

Deliver the following portions into 250-ml. flasks. Make up to volume with distilled water and mix well.

Soil Phosphate Standards	95% ethyl alcohol (ml. solution required)	Sol'n 2A	Sol'n A	Sol'n B	Sol'n C	Sol'n D	Total Volume
X—High	100	0	26	8.0	5.2	0	250 ml.
X—Medium	100	0	17	4.5	3.0	0	250 ml.
X—Doubtful	100	0	11	3.5	2.0	0	250 ml.
X—Low	0	0	0	0	0	0	250 ml.
Y—High	100	0	30	10.0	5.0	0	250 ml.
Y—Medium	100	0	20	7.0	4.0	0	250 ml.
Y—Doubtful	100	0	11	4.0	1.5	0	250 ml.
Y—Low	50	0	0	2.5	0	0	250 ml.
H.R. I	100	0	26	8	5.2	0	250 ml.
H.R. II	100	22.5	0	10.8	6.0	0	250 ml.
H.R. III	100	36.0	0	15.0	8.0	0	250 ml.
H.R. IV	70	52.0	0	15.0	7.0	23	250 ml.
H.R. V	60	50.0	0	18.0	15.0	30	250 ml.
H.R. VI	60	50.0	0	20.0	21.0	30	250 ml.
H.R. VII	30	50.0	0	21.0	18.0	41	250 ml.

Cane Juice Standards	95% ethyl alcohol (ml. solution required)	Sol'n 2A	Sol'n A	Sol'n B	Sol'n C	Sol'n D	Total Volume
1	100	0	13	6	3.3	0	250 ml.
2	100	0	18	6	4.0	0	250 ml.
3	100	0	26	8	5.2	0	250 ml.
4	100	0	32	8.5	5.0	0	250 ml.
5	100	22.5	0	10.8	6.0	0	250 ml.
6	100	29.0	0	13.0	7.0	0	250 ml.
7	100	36.0	0	15.0	8.0	0	250 ml.
8	100	42.0	0	15.0	8.0	0	250 ml.

The R.C.M. Determination of Total Nitrogen in Plant Material

This method is intended to supplement the more elaborate procedure described in the previous paper (2). In the latter method, the above-ground portion of the plant was collected, dried and then ground to a granular powder in a power mill. Several objections were found to the procedure. In the first place, the freshly collected material was bulky and required unusual care and space in the process of air-drying to protect it from dust, dirt, and fermentation. Secondly, it was difficult to disintegrate properly preparatory to grinding. Thirdly, a field nitrogen study, carried on during a crop cycle, entailed the removal from the field of no inconsiderable amount of cane. The removal of sampled material not only broke the continuity of the cane row, but allowed greater access of air and light to the remaining crop which later was to be used in the course of the study.

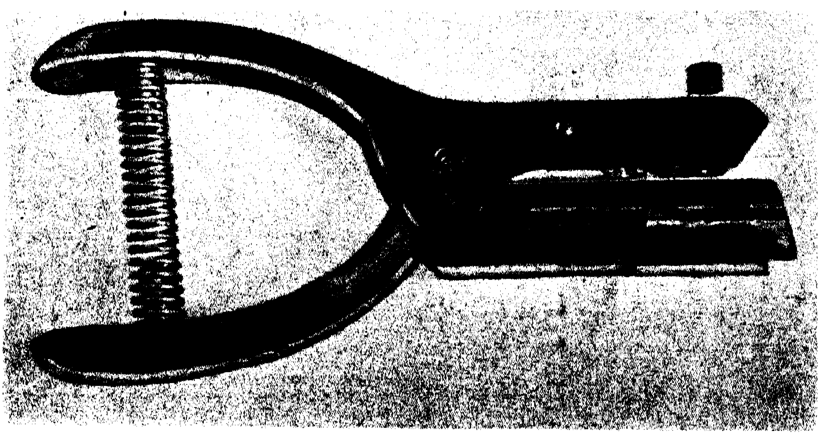
In spite of these objections, the procedure does have certain outstanding merits and is being used at the present time in a number of plantation research projects.

The modification which is described here eliminates entirely the removal of any appreciable amount of the crop and also the necessity of preparation and drying of samples for analysis.

In the life of a growing cane crop, from its earliest stages to its maturity, the major chemical activity in the plant takes place within the leaf tissue. It was believed, therefore, that absorption of plant nutrients from the soil by the crop should

be reflected from time to time by changes in the relative or total amounts of absorbed nutrients and moisture found in the leaf tissue of the plant. The work of A. Ayres, Assistant Chemist, and other investigators at this Experiment Station has shown marked differences in the nitrogen composition of the younger and older green leaves of the cane plant. In his study on sampling technic for the method under discussion, L. E. Davis, Associate Chemist, proposed, in due course, that, counting from the top of the plant, the third to the seventh leaves constituted a region from which samples may be secured for analysis which may quite satisfactorily represent the nutrient constituents present in the crop at given stages in its development.

Some years ago, the late Y. Kutsunai, Associate Agriculturist of this Experiment Station, developed a method of leaf sampling by cutting small discs in the growing leaves, using an ordinary ticket punch. This "ticket punch" system of sampling was adopted by Mr. Davis for the present procedure. The advantages over the older technic are many. A cane leaf appears to withstand a number of punch-hole removals of tissue without doing it any noticeable injury. Therefore, in a study of a growing crop, the investigator may return to the same plant, or more directly, to the same leaf, in sampling at progressive intervals of its growth. No damage is done to the crop thereby and no breaks are made in the continuity of the crop line. Fifty or more discs may constitute a sample adequate for analysis. The ticket punch which is used carries a tightly fitting receptacle which automatically collects the punched specimens. The collected green-leaf discs may be placed in a small air-tight, metal, tared container, weighed on a balance and then introduced directly to the Kjeldahl flask for digestion. No drying, grinding or other preparation for analysis is required. A photograph of the punch used in this work appears herein. It may be purchased for $3.00.



Ticket punch for sampling cane leaves.

Equipment Required

Nitrogen-in-cane-juice assembly, with the exception of:
1 pipette (bacteriological), 1 ml.
2 juice screens.
2 beakers, Pyrex glass, 600 ml.
2 beakers, Pyrex glass, 400 ml.
1 pipette, volumetric, 25 ml.
¼ lb. cane juice preservative.

In addition there will be needed:
1 balance, analytical, sensitive to 2 mg.
1 punch, with receptacle, $^3/_{16}$″-¼″ die.
12 beakers, Pyrex glass, 50 ml.
2 doz. tin boxes, ¼ oz., with tight-fitting covers.

Procedure

1. Obtain samples in the field from growing cane.

2. Confine attention to stalks bearing at least 6 leaves.

3. Sample the third, fourth and fifth leaves on each stalk selected (counting the spindle, or first incompletely unfurled leaf, as the first leaf). Punch one disc from each leaf at a point about midway from tip to base and about midway from margin to midrib.

4. Sample 15 to 25 stalks representing 45 to 75 discs, or between 0.2 and 0.4 gram of green tissue.

5. Transfer discs to a small tin box and cover tightly.

6. Weigh the box with cover and contents. Transfer the discs to a Kjeldahl flask, 300-ml. capacity. Weigh the cover and box again. The difference in weight represents the green weight of the sample. Record the weights.

7. Proceed with Steps 1-b to 8 of the procedure for the rapid estimation of nitrogen in cane juices.

8. Pipette 5 ml. of the distillate into a clean, dry 50-ml. beaker. Add 25 ml. of Reagent 18, total N, and mix.

9. Pipette 5 ml. of the diluted solution into each of 2 comparison vials. Add one ml. of Reagent 6, N to each with the special pipette. Stopper and let stand one minute.

10. Compare on the illuminator with the ammonia nitrogen in soil color standards.

11. Refer to the table below of Percentage Nitrogen in Cane Leaves.

PER CENT TOTAL NITROGEN IN CANE LEAVES

(Green-weight basis)

5 ml. distillate—25 ml. Reagent 18, total N

Green weight	Reading, tube number						
Grams	2	3	4	5	6	7	8
.200	.18	.30	.42	.54	.72	.90	1.20
.205	.18	.29	.41	.53	.70	.88	1.17
.210	.17	.29	.40	.51	.69	.86	1.14
.215	.17	.28	.39	.50	.67	.84	1.12
.220	.16	.27	.38	.49	.66	.82	1.09
.225	.16	.27	.37	.48	.64	.80	1.07
.230	.16	.26	.37	.47	.63	.78	1.04
.235	.15	.26	.36	.46	.61	.77	1.02
.240	.15	.25	.35	.45	.60	.75	1.00
.245	.15	.25	.34	.44	.59	.73	.98
.250	.14	.24	.34	.43	.58	.72	.96
.255	.14	.24	.33	.42	.56	.71	.94
.260	.14	.23	.32	.42	.55	.69	.92
.265	.14	.23	.32	.41	.54	.68	.90
.270	.13	.22	.31	.40	.53	.67	.89
.275	.13	.22	.31	.39	.52	.66	.87
.280	.13	.21	.30	.39	.51	.64	.86
.285	.13	.21	.29	.38	.51	.63	.84
.290	.12	.21	.29	.37	.50	.62	.83
.295	.12	.20	.28	.37	.49	.61	.81
.300	.12	.20	.28	.36	.48	.60	.80
.305	.12	.20	.28	.35	.47	.59	.79
.310	.12	.19	.27	.35	.47	.58	.78
.315	.11	.19	.27	.34	.46	.57	.76
.320	.11	.19	.26	.34	.45	.56	.75
.325	.11	.18	.26	.33	.44	.55	.74
.330	.11	.18	.25	.33	.44	.55	.73
.335	.11	.18	.25	.32	.43	.54	.72
.340	.11	.18	.25	.32	.42	.53	.71
.345	.10	.17	.24	.31	.42	.52	.70
.350	.10	.17	.24	.31	.41	.51	.69
.355	.10	.17	.24	.30	.41	.51	.68
.360	.10	.17	.23	.30	.40	.50	.67
.365	.10	.16	.23	.30	.39	.49	.66
.370	.10	.16	.23	.29	.39	.49	.65
.375	.10	.16	.22	.29	.38	.48	.64
.380	.09	.16	.22	.28	.38	.47	.63
.385	.09	.16	.22	.28	.37	.47	.62
.390	.09	.15	.22	.28	.37	.46	.61
.395	.09	.15	.21	.27	.36	.46	.61
.400	.09	.15	.21	.27	.36	.45	.60

The R.C.M. Determination of Potash and Phosphate in Cane Leaves*

In addition to the determination of nitrogen in cane leaves, R.C.M. procedures have been developed for estimations of potash and phosphate, using ticket punch samples.

Equipment Required

Potash-and-phosphate-in-cane-juice assemblies, with the exception of the following items, which are not required:

12 funnels, short stem, 90 mm. dia.
1 box Whatman No. 12, 18.5-cm. folded filter paper.
1 pipette, transfer, straight type, 1 ml.
2 pipettes, medicine dropper, calib. 1 ml.
¼ lb. cane juice preservative.
1 pipette, special, 5 ml.
2 pipettes, volumetric, Exax, 5 ml.

In addition, there will be needed:

1 balance, analytical, sensitive to 2 mg.
1 punch, with receptacle, 3/16"-¼" die.
36 beakers, Pyrex glass, 100 ml.
2 doz. tin boxes, ¼ oz., with tight-fitting covers.
½ lb. conc. nitric acid, special, in g.s.b.**
½ lb. conc. hydrochloric acid, special, in g.s.b.**
12 funnels, glass, 65 mm. dia.**
1 pkg. Munktell No. 3, 11-cm. filter paper.**
2 dropping bottles, with T. K. stoppers, 30 ml.**
1 electric hot plate.**
1 pipette, volumetric, 10 ml.**
1 pipette, volumetric, 25 ml.
2 pipettes, Mohr 1 ml., marked to deliver in 0.1 ml. portions.
1 gal. Reagent 8, N.
12 cover glasses, 2½" dia.
12 stirring rods, 4-inch length.

Procedure

Preparation of Sample

1. Obtain samples in the field from growing cane.
2. Confine attention to stalks bearing at least 6 leaves.
3. Sample the third, fourth and fifth leaves on each stalk selected (counting the spindle, or first incompletely unfurled leaf, as the first leaf). Punch one disc from each leaf at a point about midway from tip to base and about midway from margin to midrib.
4. Sample 15 to 25 stalks, representing 45 to 75 discs, or between 0.2 and 0.4 gram of green tissue.

Note: It is not necessary to obtain more than one specimen for potash and phosphoric acid, or 2 where nitrogen estimations are also desired. However, it will not take long to obtain an additional sample, which will then be available in case of an accident or exceptionally low values for potash or phosphate.

* Refer to directions for potash and phosphate in cane juice for analytical detail not repeated here (2).

** Note: Items included in soil potash or phosphate assemblies.

5. Transfer discs to a small tin box and cover tightly.

6. Weigh the box with cover and contents. Transfer the discs to a 100-ml. beaker. Weigh the cover and box again. The difference in weight represents the green weight of the sample. Record the weights.

7. Add to the beaker 10 drops conc. nitric acid and 30 drops conc. hydrochloric acid. Cover with a 2½″ cover glass and place on an electric hot plate at low heat. After 5 minutes, remove the cover and allow the liquid to evaporate almost to dryness. Stir with a stirring rod towards the end to macerate the tissue and to avoid scorching.

8. Repeat Step 7 twice. Finally, allow the contents to become as nearly dry as possible without scorching. Cool.

9. Add 50 ml. Reagent 8, N from 250-ml. dispensing burette.

10. Stir thoroughly and filter through a dry 11-cm. filter paper into a 100-ml. beaker.

11. Transfer 25 ml. of the filtrate to a 100-ml. beaker and 10 ml. to a 50-ml. beaker. Evaporate to dryness. *Avoid scorching.*

12. Add 5 drops conc. nitric acid and again evaporate to dryness. Repeat 6—8 times.

13. Add 10 drops conc. hydrochloric acid and evaporate to dryness. Repeat twice. Cool.

Estimation of Potash

1. Add 5 ml. of Reagent 10, K_2O to the 100-ml. beaker previously containing 25 ml. of the filtrate from Step 11 above. Stir thoroughly.

2. Transfer 1 ml. to a potash vial with a pipette marked to deliver in 0.1-ml. portions and proceed according to the directions for potash in soil, Steps 7—13.

3. If a reading of 3 is obtained, repeat Step 2, using instead of 1 ml., 0.8, 0.6, 0.4, 0.3 or 0.2 ml. with 0.2, 0.4, 0.6, 0.7 or 0.8 ml. of Reagent 10, K_2O, respectively (to make a volume of 1.0 ml.), until a reading of 2 is obtained. Refer to the table and average the results.

4. If a reading of 4 is obtained with 1 ml. of the solution, employ different aliquots until readings of both 2 and 3 are obtained. Refer to the table and average the results.

5. If readings of 2 or 1 are obtained with 1 ml. of the solution, it will be necessary to prepare a fresh sample, according to Steps 1—10 (Preparation of Sample), and in Step 11 to transfer 45 ml. of the filtrate instead of 25 ml. Then proceed as above. Multiply values obtained from the table by the factor 0.56 to obtain the percentages of potash.

Estimation of Phosphate

1. Add 8.5 ml. of Reagent 4, P_2O_5 from a 50-ml. burette to the 50-ml. beaker previously containing 10 ml. of the filtrate from Step 11 (Preparation of Sample). Stir thoroughly.

2. Transfer entire contents to a phosphate vial.

3. Add one drop of stannous chloride ~~solution~~. Shake and immediately compare with the phosphate color standards for cane juice, using the P_2O_5 illuminator. Note result. Then add another drop of stannous chloride solution, shake and make comparison again. Refer to the table for percentage of P_2O_5 in the sample.

4. If the color is too dark for comparison, return to Step 11 (Preparation of Sample) and transfer 5 ml. of the solution to a 50-ml. flask. Proceed with Steps 12 and 13 as before. Finally, multiply all values obtained from the table by 2 to obtain the correct percentage of P_2O_5.

5. If the color is too light for comparison, it will be necessary to prepare a fresh sample according to directions. In Step 11, transfer 20 ml. to a 50-ml. beaker and proceed. Finally, multiply values obtained from the table by 0.5 to obtain the true percentage of P_2O_5.

PERCENTAGE OF POTASH IN CANE LEAVES
(Green-weight basis)
50 ml. Reagent 8, N, 25 ml. filtrate, 5 ml. Reagent 10, K_2O

Green weight Grams	1 ml. Readings 2	1 ml. 3	.8 ml. 2	.8 ml. 3	.6 ml. 2	.6 ml. 3	.4 ml. 2	.4 ml. 3	.3 ml. 2	.3 ml. 3	.2 ml. 2	.2 ml. 3
.28	.27	.30	.33	.38	.45	.51	.67	.76	.89	1.01	1.34	1.52
.29	.26	.29	.32	.37	.43	.49	.65	.73	.86	.98	1.29	1.47
.30	.25	.28	.31	.35	.42	.47	.62	.71	.83	.94	1.25	1.42
.31	.24	.27	.30	.34	.40	.46	.61	.69	.81	.91	1.21	1.37
.32	.23	.27	.29	.33	.39	.44	.59	.66	.78	.88	1.17	1.33
.33	.23	.26	.28	.32	.38	.43	.57	.64	.76	.86	1.14	1.29
.34	.22	.25	.28	.31	.37	.42	.55	.62	.74	.83	1.10	1.25
.35	.22	.25	.27	.31	.36	.40	.54	.61	.71	.81	1.07	1.21
.36	.21	.24	.26	.30	.35	.39	.52	.59	.69	.79	1.04	1.18
.37	.20	.23	.25	.29	.34	.38	.51	.57	.68	.76	1.01	1.15
.38	.20	.22	.25	.28	.33	.37	.49	.56	.66	.74	.99	1.12
.39	.19	.22	.24	.27	.32	.36	.48	.54	.64	.73	.96	1.09
.40	.19	.21	.23	.27	.31	.35	.47	.53	.63	.71	.94	1.06

PERCENTAGE OF PHOSPHATE IN CANE LEAVES
(Green-weight basis)
50 ml. Reagent 8, 10 ml. filtrate, 8.5 ml. Reagent 4, P_2O_5

Green weight Grams	Color Standard Tube No. 1	2	3	4	5	6	7	8
.28	.057	.086	.114	.143	.171	.200	.229	.257
.29	.055	.083	.110	.138	.166	.193	.221	.248
.30	.053	.080	.107	.133	.160	.187	.213	.240
.31	.052	.077	.103	.129	.155	.181	.206	.232
.32	.050	.075	.100	.125	.150	.175	.200	.225
.33	.048	.073	.097	.121	.145	.170	.194	.218
.34	.047	.071	.094	.118	.141	.165	.188	.212
.35	.046	.069	.091	.114	.137	.160	.183	.206
.36	.044	.067	.089	.111	.133	.156	.178	.200
.37	.043	.065	.086	.108	.130	.151	.173	.195
.38	.042	.063	.084	.105	.126	.147	.168	.190
.39	.041	.061	.082	.103	.123	.144	.164	.185
.40	.040	.060	.080	.100	.120	.140	.160	.180

The Estimation of Nutrients in Alkaline Soils

Soils which are very alkaline or contain very large amounts of carbonates should not be analyzed for potash and phosphate by the regular R.C.M. procedures. There are several reasons which render data invalid when so obtained. The major difficulty is associated with side reactions which take place when the weakly acidified

soil extraction solution is brought in contact with the alkaline soil. Analyses of soils in this category for readily soluble nutrients, by extraction with extremely dilute acid solvents, are, at the very best, but little short of a compromise. However, modifications may be made to the standard procedure which compensate, to a degree, for the interfering alkalinity or excess of calcium and other carbonates.

*Rapid Estimation of Phosphate in Soils High in Calcium and Other Carbonates:**

Important: Use this procedure *only* when there is any effervescence upon the addition of N/2 hydrochloric acid solution to the soil in the regular procedure. Usually, soils of this type have a pH greater than 7.5.

Additional Equipment Required

1 gal. N/1 hydrochloric acid solution.
1 qt. 0.15 normal sodium hydroxide solution.
60 ml. methyl red indicator solution.
1 dropping bottle, pipette stopper with nipple, 60 ml.
1 pipette, 5 ml.

Procedure

During the course of the regular procedure for the Rapid Estimation of Phosphate in Soils, if there is any effervescence on the addition of N/2 hydrochloric acid solution to the 10 grams of soil, proceed as follows:

1. Filter immediately after swirling for ½ minute.
2. Transfer 5 ml. of the filtrate into a 100-ml. beaker by means of a 5-ml. pipette.
3. Add 2 drops of methyl red indicator, which imparts a pink or reddish color to the solution.
4. Then, with another 5-ml. pipette, add 5 ml. of the 0.15 normal sodium hydroxide solution and swirl the contents of the beaker.
5. A—If the pink color does not disappear, transfer a 10-ml. portion of the remaining filtrate to a 50-ml. beaker. Then continue with the usual treatment as in the procedure for the Rapid Estimation of Phosphate in Soils, beginning with Step 6.

   B—If the pink color disappears, discard the remaining filtrate and extract 10 grams of the soil with a one-normal hydrochloric acid solution by swirling for ½ minute. Then immediately filter and continue from Step 5 in the regular procedure for the Rapid Estimation of Phosphate in Soils.

*Rapid Estimation of Potash in Soils High in Calcium:**

Important: Use this supplementary procedure *only when flocs or coarse aggregates appear* in the solution after Reagent 2, K_2O and Reagent 3, K_2O have been added and the vial shaken in the rotator.

*A supplementary procedure. Refer to standard procedure for analytical details not included below (2).

Additional Equipment Required

1 pt. Reagent 14, Ca.
1 pkg. Whatman No. 2, 7-cm. filter paper.

Procedure

1. Proceed with Steps 1 to 5 as outlined in the procedure for the Rapid Estimation of Potash in Soils.
2. With the calibrated medicine dropper, transfer a 3-ml. portion of the filtrate to a clean vial.
3. Add 2 drops of Reagent 14, Ca and mix. Add 2 more drops of Reagent 14, Ca and mix. Finally, add another 2 drops of the reagent and mix so that to each ml. of filtrate, 2 drops of Reagent 14, Ca, are added.
4. Filter through Whatman No. 2, 7-cm. filter paper into another vial.
5. Using this final filtrate, continue with Steps 6 to 14, as described in the procedure for the Rapid Estimation of Potash in Soils.
6. If coarse aggregates or flocs are still formed in the final solution after 2 drops of Reagent 14, Ca have been added to each ml. of the filtrate, take another 3-ml. portion of the original filtrate and add 4 drops of Reagent 14, Ca to each ml. of filtrate. If flocs still appear in the final solution, add 6, 8 or more drops of Reagent 14, Ca to each ml. of the filtrate, as necessary, and continue as directed in Step 3 until the final solution presents a uniform turbidity.
7. Refer to the table which follows for soils high in calcium to obtain corrected results.

RAPID ESTIMATION OF POTASH IN SOILS

(Supplementary procedure for soils high in calcium)

Number of drops of Reagent 14, Ca added to each ml. of filtrate

Ratio Soil: Reagent	Reading	2 Per Cent	2 lb/ a-ft.	4 Per Cent	4 lb/ a-ft.	6 Per Cent	6 lb/ a-ft.	8 Per Cent	8 lb/ a-ft.	10 Per Cent	10 lb/ a-ft.	15 Per Cent	15 lb/ a-ft.	20 Per Cent	20 lb/ a-ft.	25 Per Cent	25 lb/ a-ft.	30 Per Cent	30 lb/ a-ft.
20g: 20 ml.	1	<.003	<75	<.003	<75	<.004	<100	<.004	<100	<.004	<100	<.004	<100	<.005	<125	<.005	<125	<.006	<150
	2	.003	75	.003	75	.004	100	.004	100	.004	100	.004	100	.005	125	.005	125	.006	150
	3	.004	100	.004	100	.005	125	.005	125	.005	125	.005	125	.006	150	.007	175	.008	200
	4	>.004	>100	>.004	>100	>.005	>125	>.005	>125	>.005	>125	>.005	>125	>.006	>150	>.007	>175	>.008	>200
15g: 20 ml.	1	<.004	<100	<.004	<100	<.005	<125	<.005	<125	<.005	<125	<.005	<125	<.006	<150	<.007	<175	<.008	<200
	2	.004	100	.004	100	.005	125	.005	125	.005	125	.005	125	.006	150	.007	175	.008	200
	3	.005	125	.006	150	.006	150	.006	150	.007	175	.007	175	.008	200	.009	225	.010	250
	4	>.005	>125	>.006	>150	>.006	>150	>.006	>150	>.007	>175	>.007	>175	>.008	>200	>.009	>225	>.010	>250
10g: 20 ml.	1	<.006	<150	<.007	<175	<.007	<175	<.007	<175	<.008	<200	<.009	<225	<.010	<250	<.011	<275	<.011	<275
	2	.006	150	.007	175	.007	175	.007	175	.008	200	.009	225	.010	250	.011	275	.011	275
	3	.007	175	.008	200	.008	200	.009	225	.009	225	.010	250	.011	275	.012	300	.013	325
	4	>.007	>175	>.008	>200	>.008	>200	>.009	>225	>.009	>225	>.010	>250	>.011	>275	>.012	>300	>.013	>325
7.5g: 20 ml.	1	<.010	<250	<.010	<250	<.011	<275	<.011	<275	<.012	<300	<.013	<325	<.014	<350	<.016	<400	<.017	<425
	2	.010	250	.010	250	.011	275	.011	275	.012	300	.013	325	.014	350	.016	400	.017	425
	3	.011	275	.011	275	.012	300	.012	300	.013	325	.015	375	.016	400	.018	450	.019	475
	4	>.011	>275	>.011	>275	>.012	>300	>.012	>300	>.013	>325	>.015	>375	>.016	>400	>.018	>450	>.019	>475
2.5g: 10 ml.	1	<.013	<325	<.013	<325	<.014	<350	<.015	<375	<.016	<400	<.017	<425	<.019	<475	<.021	<525	<0.23	<575
	2	.013	325	.013	325	.014	350	.015	375	.016	400	.017	425	.019	475	.021	525	.023	575
	3	.015	375	.016	400	.017	425	.017	425	.018	450	.020	500	.022	550	.025	625	.027	675
	4	>.015	>375	>.016	>400	>.017	>425	>.017	>425	>.018	>450	>.020	>500	>.022	>550	>.025	>625	>.027	>675

RAPID ESTIMATION OF POTASH IN SOILS

(Supplementary procedure for soils high in calcium)

Ratio Soil: Reagent	Read-ing	Number of drops of Reagent 14, Ca added to each ml. of filtrate: 2		4		6		8		10	
		Per Cent	lb/ a-ft.	Per Cent	lb/ a-ft.	Per Cent	lb/ a-ft.	Per Cent	lb/ a-ft.	Per Cent	lb/ a-ft.
2.5g: 15 ml.	1	<.019	<475	<.020	<500	<.021	<525	<.022	<550	<.023	<575
	2	.019	475	.020	500	.021	525	.022	550	.023	575
	3	.022	550	.024	600	.025	625	.026	650	.027	675
	4	>.022	>550	>.024	>600	>.025	>625	>.026	>650	>.027	>675
2.5g: 20 ml.	1	<.027	<675	<.028	<700	<.030	<750	<.031	<775	<.033	<825
	2	.027	675	.028	700	.030	750	.031	775	.033	825
	3	.030	750	.031	775	.033	825	.035	875	.036	900
	4	>.030	>750	>.031	>775	>.033	>825	>.035	>875	>.036	>900
2.5g: 25 ml.	1	<.033	<825	<.035	<875	<.037	<925	<.039	<975	<.040	<1000
	2	.033	825	.035	875	.037	925	.039	975	.040	1000
	3	.037	925	.039	975	.041	1025	.043	1075	.046	1150
	4	>.037	>925	>.039	>975	>.041	>1025	>.043	>1075	>.046	>1150
2.5g: 30 ml.	1	<.039	<975	<.041	<1025	<.044	<1100	<.046	<1150	<.048	<1200
	2	.039	975	.041	1025	.044	1100	.046	1150	.048	1200
	3	.045	1125	.047	1175	.050	1250	.052	1300	.055	1375
	4	>.045	>1125	>.047	>1175	>.050	>1250	>.052	>1300	>.055	>1375
2.5g: 35 ml.	1	<.047	<1175	<.049	<1225	<.052	<1300	<.055	<1375	<.057	<1425
	2	.047	1175	.049	1225	.052	1300	.055	1375	.057	1425
	3	.052	1300	.055	1375	.058	1450	.061	1525	.064	1600
	4	>.052	>1300	>.055	>1375	>.058	>1450	>.061	>1525	>.064	>1600
2.5g: 40 ml.	1	<.053	<1325	<.056	<1400	<.059	<1475	<.062	<1550	<.065	<1625
	2	.053	1325	.056	1400	.059	1475	.062	1550	.065	1625
	3	.059	1475	.063	1575	.066	1650	.070	1750	.073	1825
	4	>.059	>1475	>.063	>1575	>.066	>1650	>.070	>1750	>.073	>1825

Rapid Estimation of Calcium in Cane Juice*

1. To a pint of fresh cane or crusher juice, add 2 heaping spoonfuls (small horn spoon) of R.C.M. cane juice preservative and shake well.
2. Allow the treated juice to stand for at least ½ hour.
3. Filter through Whatman No. 12, 15-cm. folded filter paper and collect at least 20 ml. of filtrate before proceeding.
4. By means of a 2-ml. Mohr pipette (for R.C.M. CaO), transfer a suitable aliquot—1.0 to 2.0 ml.—of the filtrate to a short-form shell vial (K_2O type).
5. Then add enough Reagent 13, Ca to bring the total volume to 3 ml., using a burette.
6. To the contents of the shell vial add 1 ml. of Reagent 14, Ca and immediately close the tube with the thumb and shake it with sufficient rapidity to insure 40 shakes in 8 seconds.
7. Let stand for *one minute.*
8. Make the reading as in the Rapid Estimation of Calcium in Soils and record the "2" and "3" readings registered by the *smallest* aliquots taken from the sample.
9. Refer to the table and obtain the concentration of calcium in terms of per cent CaO by volume or pounds of CaO per ton of juice in the original sample.

Example:

Aliquots	Readings	
1.0	1	
1.1	2—0.17 per cent	
1.2	2	
1.3	2	Avg. 0.18 per cent CaO,
1.4	2	or 34 lbs. per ton of juice.
1.5	3—.018 per cent	

10. In case the tested juice is higher (1 ml. = 3 reading), or lower (2 ml. = 2 reading) in CaO, dilute or concentrate the juice as follows:

To dilute: Mix thoroughly 10 ml. of filtered juice with 10 ml. of distilled water and proceed as described. When reading is made with this solution, refer to Table II.

To concentrate: Transfer 40 ml. of filtered juice into a 100-ml. beaker. Evaporate approximately to less than half of the original volume on an electric hot plate. Cool and carefully transfer the concentrated juice to a 25-ml. graduated cylinder and add washings from the beaker to the 20-ml. mark.

Mix well before using. Refer readings to Table III.

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*Refer to R.C.M. for calcium in soil for analytical details not included below (2).

RAPID ESTIMATION OF CALCIUM (CAO) IN CANE JUICE

(For Approximate Determination)

ml. aliquots of cane juice

Readings		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Table I—Cane Juice																					
3	Per Cent	.26	.13	.087	.065	.052	.043	.037	.033	.029	.027	.025	.023	.021	.020	.018	.017	.016	.015	.015	.014
	lb per ton	4.81	2.41	1.61	1.20	0.96	0.80	0.69	0.60	0.54	0.50	0.46	0.42	0.39	0.36	0.34	0.32	0.30	0.29	0.27	0.26
2	Per Cent	.18	.090	.060	.045	.036	.030	.026	.023	.020	.019	.017	.016	.015	.014	.013	.012	.012	.011	.011	.010
	lb per ton	3.33	1.67	1.11	0.83	0.67	0.56	0.47	0.42	0.37	0.35	0.32	0.30	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18
Table II—Diluted cane juice, 10 ml. cane juice + 10 ml. distilled water																					
3	Per Cent										.052	.047	.043	.040	.037	.035	.033	.031	.029	.027	.026
	lb per ton										0.96	0.88	0.80	0.74	0.69	0.64	0.60	0.57	0.54	0.51	0.48
2	Per Cent										.036	.033	.030	.028	.026	.024	.023	.021	.020	.019	.018
	lb per ton										0.67	0.61	0.56	0.51	0.47	0.44	0.42	0.39	0.37	0.35	0.33
Table III—Concentrated cane juice, 40 ml. cane juice conc. to 20 ml.																					
3	Per Cent										.015	.014	.013	.012	.011	.011	.010	.010	.009	.009	.008
	lb per ton										0.28	0.26	0.24	0.22	0.21	0.20	0.19	0.18	0.18	0.16	0.16
2	Per Cent										.011	.010	.010	.009	.008	.008	.008	.007	.007	.007	.006
	lb per ton										0.20	0.19	0.18	0.16	0.16	0.15	0.14	0.14	0.13	0.12	0.12

Rapid Estimation of Calcium in Irrigation or Other Water

Equipment Required

6 beakers, Pyrex glass, 400 ml.*
1 funnel rack, 10 hole.*
6 funnels, glass, 90 mm. dia.*
1 box Whatman No. 12, 15-cm. folded filter paper.*
1 cylinder, graduated, 100 ml.*
6 beakers, Pyrex glass, 250 ml.*
3 special pipettes, 2-ml. capacity (for Reagent 7, N).*
6 glass rods, 4½" length.
1 dispensing burette, 250 ml.*
1 pkg. Munktell No. 3 (9- or 11-cm.) filter paper.*
1 pipette, Mohr 2 ml. (for CaO in soil).*
1 burette, 50 ml.*
1 dispensing bottle for Reagent 14, Ca with dropper calibrated to 1 ml.*
1 calcium illuminator.*
12 short-form shell vials.*
1 electric hot plate.*
6 funnels, glass, 65 mm. dia.*
6 beakers, Pyrex glass, 50 ml.*
1 lb. conc. nitric acid, special, in g.s.b.*
1 lb. conc. hydrochloric acid, special, in g.s.b.*
1 pt. Reagent 23, Ca in g.s.b.
1 gal. Reagent 13, Ca.*

General Procedure

Collect one gallon of water as representative of the sample to be analyzed. Thoroughly mix in bottle and filter about 250 ml. through a Whatman No. 12, 15-cm. folded filter paper.

1. Using a 100-ml. graduate, transfer 100 ml. of the filtered sample to a 250-ml. beaker and evaporate to dryness.
2. Add 2 ml. of conc. nitric acid and 2 ml. of conc. hydrochloric acid from a special pipette (for Reagent 7, N). Evaporate to dryness.
3. Add 2 ml. of conc. hydrochloric acid, using the same pipette. Evaporate to dryness. Allow residue to cool.
4. Add 2 ml. of Reagent 23, Ca. (If the same pipette is used, it must be thoroughly washed and at least partially dried. It may be more convenient to have 3 of these pipettes.)
5. Stir thoroughly by means of a glass rod and introduce from a dispensing burette 23 ml. of Reagent 13, Ca.
6. Mix well and filter through Munktell No. 3 (9- or 11-cm.) filter paper into a 50-ml. beaker.

***Items included in other R.C.M. assemblies.**

Approximate Determination

7. Using a 2-ml. Mohr pipette (for R.C.M.CaO), transfer successive aliquots of 0.1 to 1 ml. into potash vials.

8. Make the volume to 2 ml. by adding Reagent 13, Ca from a 50- or 25-ml. burette.

9. Add 1 ml. of Reagent 14, Ca and, closing the vial with the thumb, shake vigorously and with sufficient rapidity to insure 30 shakes in 7 seconds.

10. Let stand ½ minute and make readings as in R.C.M. calcium-in-soil procedure, recording the "2" and "3" readings registered by the smallest aliquots taken from the sample.

11. Refer to Table I and average the concentrations corresponding to the recorded readings.

Accurate Determination

12. Referring to the results of the approximate analysis, make dilutions, according to the following table:

Per Cent CaO	Dilution	For results
.0045 or less	Proceed without dilution	Refer to Table II
.0045—.0090	1 part sol'n to 1 part No. 13, Ca	Refer to Table III
.0090—.018	1 part sol'n to 3 parts No. 13, Ca	Refer to Table IV
.018 —.036	1 part sol'n to 7 parts No. 13, Ca	Refer to Table V

13. Transfer a suitable aliquot (1 to 3 ml.) to a potash vial and make up volume to 3 ml. with Reagent 13, Ca.

14. Add 1 ml. of Reagent 14, Ca; immediately close the vial with the thumb and shake with sufficient rapidity to insure 40 shakes in 8 seconds.

15. Let stand one minute and make readings as in the Rapid Estimation of Calcium in Soils, recording the "2" and "3" readings registered by the smallest aliquots.

16. Refer to the correct table for the concentration of calcium corresponding to the readings and take the average of the two.

17. In case the sample contains less than .0022 per cent of CaO and yet an accurate determination is required, start again from Step 1, but use a greater volume of sample (200, 300 or 500 ml.) and divide the final result by a factor obtained by dividing the volume of the sample by 100.

18. In case the sample contains more than .036 per cent of CaO, supplementary directions and a data chart may be prepared and furnished upon request.

RAPID ESTIMATION OF CALCIUM IN WATER

(Results expressed as per cent and pounds per million gallons)

Table I—Approximate Determination

Readings	Aliquots..	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Reading 3	....	.065	.033	.022	.016	.013	.011	.0093	.0081	.0072	.0065
	....	5425	2754	1836	1335	1085	918	776	675	601	543
Reading 2	....	.045	.023	.015	.011	.0090	.0075	.0064	.0056	.0050	.0045
	....	3756	1920	1252	918	751	626	534	467	417	375

Table II—No Dilution

	Aliquots..	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.2	2.4	2.6	2.8	3.0
Reading 3	....	.0065	.0059	.0054	.0050	.0046	.0043	.0041	.0038	.0036	.0034	.0033	.0030	.0027	.0025	.0023	.0022
	....	543	492	451	417	384	359	342	317	300	284	275	250	225	209	192	184
Reading 2	....	.0045	.0040	.0038	.0035	.0032	.0030	.0028	.0026	.0025	.0024	.0023	.0020	.0019	.0017	.0016	.0015
	....	375	334	317	292	267	250	234	217	209	200	192	167	159	142	134	125

Table III—1 Part Solution to 1 Part Reagent 13, Ca

Reading 3	....	.013	.012	.011	.010	.0093	.0087	.0081	.0076	.0072	.0068	.0065	.0059	.0054	.0050	.0046	.0043
	....	1085	1002	918	835	776	726	676	634	601	568	543	492	451	417	384	359
Reading 2	....	.0090	.0082	.0075	.0069	.0064	.0060	.0056	.0053	.0050	.0047	.0045	.0041	.0038	.0035	.0032	.0030
	....	751	684	626	576	534	501	476	442	417	392	376	342	317	292	267	250

Table IV—1 Part Solution to 3 Parts Reagent 13, Ca

Reading 3	....	.026	.024	.022	.020	.019	.017	.016	—	.014	—	.013	.012	.011	.010	.0093	.0087
	....	2170	2003	1836	1669	1586	1419	1335	—	1169	—	1085	1002	918	835	776	726
Reading 2	....	.018	.016	.015	.014	.013	.012	.011	—	.010	—	.0090	.0082	.0075	.0069	.0064	.0060
	....	1502	1335	1252	1169	1085	1002	918	—	835	—	751	684	626	576	534	501

Table V—1 Part Solution to 7 Parts Reagent 13, Ca

Reading 3	....	.052	.047	.043	.040	.037	.035	.033	.031	.029	.027	.026	.024	.022	.020	.019	.017
	....	4340	3923	3589	3339	3088	2921	2754	2588	2421	2254	2170	2003	1836	1669	1586	1419
Reading 2	....	.036	.033	.030	.028	.026	.024	.023	.021	.020	.019	.018	.016	.015	.014	.013	.012
	....	3005	2754	2504	2337	2170	2003	1920	1753	1669	1586	1502	1335	1252	1169	1085	1002

Rapid Estimation of Lime Requirement in Soils

Equipment Required

(Additional to that required for soil reaction [pH] determinations)

12 dishes, evaporating, Coors porcelain No. 3.
12 stirring rods, 3-inch length.
1 pestle.
1 gal. Reagent 25, Ca.

Procedure

1. Obtain about 300 grams of air-dried soil which has been passed through a 2-mm. sieve. Determine its pH value, using R.C.M. (LaMotte).

2. In each of eleven 150-ml. capacity porcelain evaporating dishes place 25 grams (5, 5-gram soil cups) of the air-dried soil sample.

3. Add the following amounts of Reagent 25, Ca to the dishes and mix well:

No. of dish	ml. of Reagent 25, Ca to be added	Application equiv. to lbs. of limestone per acre-foot of soil
1	5	1,000
2	10	2,000
3	20	4,000
4	30	6,000
5	40	8,000
6	50	10,000
7	65	13,000
8	80	16,000
9	100	20,000
10	125	25,000
11	150	30,000

Amounts greater than 50 ml. should be added in small portions of 50 ml. or less to avoid loss during mixing and to hasten evaporation. In these cases, evaporate the water as described below and then add more, followed by evaporation, until the prescribed amount has been applied.

4. Place the dishes in a warm, well-ventilated place, or preferably in the current of air from an electric fan. Mix occasionally.

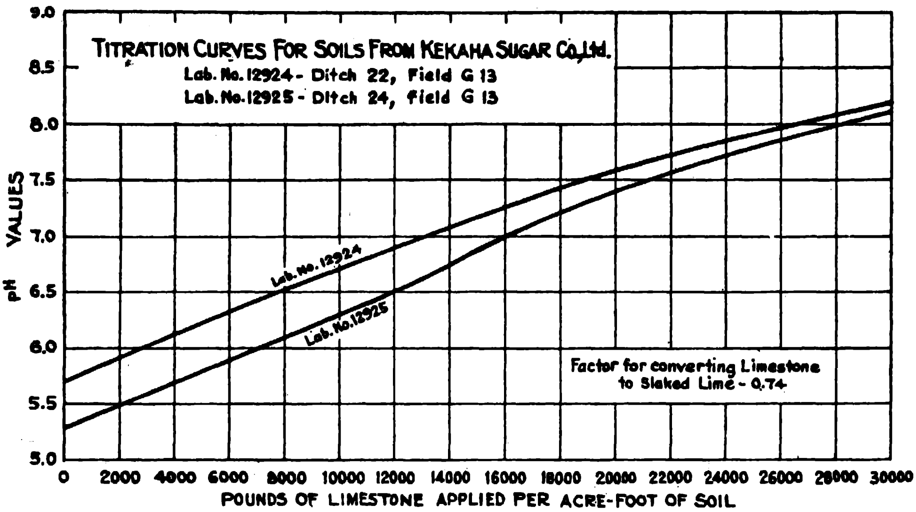
5. When the soils in the dishes are thoroughly dried, break up any large lumps with a pestle and mix well.

6. Determine the pH values on the 11 soils by R.C.M.

7. Plot on graph paper the points corresponding to the pH values against the respective treatments (expressed as pounds of limestone per acre-foot of soil) and connect these points by a smooth curve. This latter is the titration curve of the soil.

8. The amount of pure limestone required per acre to bring an acre-foot depth of soil to any desired pH within the range covered by the determination can be found by interpolation.

9. When sources of lime other than pure limestone are to be used in the field, it will be necessary to multiply the values on the curve by a factor, depending upon the composition of the material. Also, to bring a greater depth of soil to the desired pH, it is necessary to multiply the value by the depth in question, expressed in feet.



Titration curve for lime requirement in soil determination.

Rapid Determination of Replaceable Magnesium in Soils

Equipment Required

1 metal soil cup, 10 gram.*
1 metal soil cup, 5 gram.*
1 metal soil cup, 2½ gram.*
1 spatula, stainless steel, 4-inch blade.*
12 flasks, Erlenmeyer Pyrex, 125 ml.*
12 beakers, Pyrex glass, 100 ml.*
1 funnel rack, 10 hole.*
12 funnels, glass, 65 mm. dia.*
1 box Whatman No. 12, 15-cm. folded filter paper.*
1 dispensing burette, 250 ml. (with cover).*
1 pipette, Mohr 1 ml., graduated to 0.01 ml.
1 pipette, Mohr 10 ml., graduated to 0.1 ml.
12 vials, shell, tall-form.*
12 rubber stoppers, No. 00.*
1 dispensing bottle for Reagent 20, Mg. Same type as for Reagent 2, K_2O but with dropper graduated to ½ ml.
1 dispensing bottle for Reagent 21, Mg. Same type as for pH indicator solutions, but paraffined and with dropper graduated to 1 ml.
1 set magnesium-in-soil color standards (in box with rack, etc.).
1 phosphate illuminator.*
1 vial block.*
1 gal. Reagent 13, Ca.*
½ pt. Reagent 20, Mg.
1 pt. Reagent 21, Mg.

*Material included in other R.C.M. assemblies.

Procedure

1. Extract 10 grams of soil with 50 ml. of Reagent 13, Ca for one minute.
2. Filter through Whatman No. 12, 15-cm. folded filter paper.
3. Transfer into P_2O_5 vials suitable and consecutive aliquots of the extract. (.1, .2, .3, .4, .5 ml., etc., for soils containing about 0.2 per cent of replaceable MgO and 1.0, 1.25, 1.50, 1.75, 2.00 ml., etc., for soils containing about 0.02 per cent MgO.)
4. Add to each vial enough Reagent 13, Ca to bring the volume up to about one inch from the top.
5. Add ½ ml. of Reagent 20, Mg to the first vial and shake by inverting the tube 2 to 3 times.
6. Add 1 ml. of Reagent 21, Mg and shake again until the color developed is uniform throughout the vial.
7. Flip out about 1 ml. of the solution and stopper the vial with a No. 00 rubber stopper.
8. Immediately compare with the magnesium color standards on a P_2O_5 illuminator and record the reading in terms of the standard tube number.
9. Repeat Steps 5—8 with the remaining vials.
10. Refer to the data chart and record the percentages corresponding to the standard tube numbers. Up to this point, the recorded data will appear as in the following example:

Lab. No.	Extraction	Aliquot	Reading	Per Cent
12772	10-50	.1	3-4	.13—.27
		.2	5-6	.20—.33
		.3	5-6	.13—.22
		.4	6-7	.17—.23

11. Now select the maximum figure from the left column and the minimum figure from the right column and average the two. The result indicates the percentage concentration of replaceable MgO in the sample. Convert to pounds per acre-foot by multiplying by 25,000.

The concentration of replaceable MgO in the above sample is 0.21 per cent, or 5250 pounds per acre-foot.

12. Should one of the aliquots match exactly a standard, then take that result as the concentration of MgO in the sample and see whether or not this percentage agrees with that obtained by averaging, as in Step 11. If it does not, then repeat this particular aliquot to see whether or not the reading obtained is in error.

Example:

Lab. No.	Extraction	Aliquot	Reading	Per Cent	Avg.
12890	10-50	.1	3-4	.13—.27	
		.2	4-5	.13—.20	
		.3	5-6	.13—.22	.17
		.4	6	.17	
		.5	6-7	.13—.20	

In the above example, a .4-ml. aliquot gave a color matching standard No. 6 exactly, giving a concentration of .17 per cent. Averaging .13 per cent and .20 per cent also gives a concentration of .17 per cent.

13. Where the MgO concentration of a soil does not fall within the chart, the specimen may be analyzed by varying the extraction and multiplying the final result by the corresponding factor.

Soil (gm.)	Extraction sol'n (ml.)	Factors
10	50	1
5	50	2
2.5	50	4
20	50	½
30	50	⅓
40	50	¼
50	50	⅕

Precautions:

(a) The vials must be free of acids, since acids cause the color to disappear.

(b) Addition of Reagent 21, Mg causes an evolution of ammonia gas and hence determinations of ammoniacal nitrogen should be completed before determinations of MgO are undertaken.

(c) Reagent 20, Mg is unstable and for this reason should be kept in the dark when not in use. Even if kept in the dark, it should be replaced at least once a month.

(d) The standards fade gradually and should be renewed at intervals of about one month.

RAPID DETERMINATION OF MAGNESIA (MgO) IN SOILS

Per Cent and Pounds Per Acre-foot of Magnesia (MgO)

Standard No.	Aliquots in ml. .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00	4.50	5.00	6.00	7.00
1	.013	.0067	.0045	.0033	.0027	.0022	.0019	.0017	.0015	.0013	.0011	.0009	.0008	.0007	.0005	.0004	.0004		(Less than .0004%)			
	325	168	113	83	68	55	48	43	38	33	28	23	20	18	13	10	10		(Less than 10 lb)			
2	.067	.033	.023	.017	.013	.011	.0096	.0084	.0074	.0067	.0054	.0045	.0038	.0033	.0027	.0022	.0019	.0017	.0015	.0013	.0011	.0009
	1675	825	575	425	325	275	240	210	185	168	135	113	95	83	68	55	48	43	38	33	28	23
3	.13	.067	.045	.033	.027	.022	.019	.017	.015	.013	.011	.0089	.0076	.0067	.0054	.0045	.0038	.0033	.0030	.0027	.0022	.0019
	3250	1675	1125	825	675	550	475	425	375	325	275	223	190	168	135	113	95	83	75	68	55	48
4	.27	.13	.089	.067	.054	.045	.038	.033	.030	.027	.021	.018	.015	.013	.011	.0089	.0077	.0067	.0060	.0054	.0045	.0038
	6750	3250	2225	1675	1350	1125	950	825	750	675	525	450	375	325	275	223	193	168	150	135	113	95
5	.40	.20	.13	.10	.080	.067	.057	.050	.045	.040	.032	.027	.023	.020	.016	.013	.012	.010	.0089	.0080	.0067	.0057
	10000	5000	3250	2500	2000	1675	1425	1250	1125	1000	800	675	575	500	400	325	300	250	223	200	168	143
6	.67	.33	.22	.17	.13	.11	.095	.084	.074	.067	.054	.045	.038	.033	.027	.022	.019	.017	.015	.013	.011	.0096
	16750	8250	5500	4250	3250	2750	2375	2100	1850	1675	1350	1125	950	825	675	550	475	425	375	325	275	240
7	1.00	.50	.33	.25	.20	.17	.14	.13	.11	.10	.080	.067	.057	.050	.040	.033	.029	.025	.022	.020	.017	.014
	25000	12500	8250	6250	5000	4250	3500	3250	2750	2500	2000	1675	1425	1250	1000	825	725	625	550	500	425	350
8	1.34	.67	.45	.33	.27	.22	.19	.17	.15	.13	.11	.089	.076	.067	.054	.045	.038	.033	.030	.027	.022	.019
	33500	16750	11250	8250	6750	5500	4750	4250	3750	3250	2750	2225	1900	1675	1350	1125	950	825	750	675	550	475

Rapid Determination of Magnesia (MgO) in Water

Equipment Required

12 vials, shell, tall-form.*
1 pipette, Mohr 10 ml., graduated to 0.1 ml.
1 box Whatman No. 12, 15-cm. folded filter paper.*
6 beakers, Pyrex glass, 400 ml.*
1 funnel rack, 10 hole.*
6 funnels, glass, 90 mm. dia.*
1 dispensing bottle, for Reagent 22, Mg. Same type as for Reagent 2, K_2O, but with dropper graduated to ½ ml.
1 dispensing bottle, for Reagent 21, Mg. Same type as for pH indicator solutions, but paraffined and with dropper graduated to ½ ml.
1 set magnesium-in-water color standards (in box with rack, etc.).
1 phosphate illuminator.*
1 vial block.*
1 gal. distilled water.
½ pt. Reagent 22, Mg.
1 pt. Reagent 21, Mg.

General Procedure

Collect one gallon of water as representative of the sample to be analyzed. Thoroughly mix in bottle. Filter about 250 ml. through a Whatman No. 12, 15-cm. folded filter paper.

1. Transfer, by means of a 10-ml. Mohr pipette, successive aliquots (as indicated on the data chart) of the filtered sample into P_2O_5 vials.
2. Make up volume to about one inch from the top of the vial with distilled water.
3. Add ½ ml. of Reagent 22, Mg to the first vial and shake by inverting the tube 2 or 3 times.
4. Add ½ ml. of Reagent 21, Mg and shake again until the color developed is uniform throughout the vial.
5. Immediately compare with the magnesium-in-water color standards on a phosphate illuminator and record the reading in terms of the standard tube number.
6. Repeat Steps 3—5 with the remaining vials.
7. Refer to the data chart and record the concentration of MgO as percentage or as pounds per million gallons, or both, depending upon the data required.
8. Now, average the maximum figure from the left column and the minimum figure from the right column, as in the method for magnesium in soils.

***Material included in other R.C.M. assemblies.**

Example:

Aliquot in ml.	Reading	Per Cent	lb/mil.gal.
1	1-2	.0007—.0020	56—167
2	1-2	.0010—.0017	84—140
3	2-3	.0007—.0011	56— 93
4	3-4	.0008—.0012	70— 98
5	4-5	.0009—.0012	78—100
6	4-5	.0008—.0010	65— 84
7	5-6	.0009—.0010	72— 88
		Average .0010	84

9. Specimens containing over 300 pounds of MgO per million gallons may be analyzed by making a suitable dilution, using distilled water and multiplying the final result by a corresponding factor.

Parts of sample	Parts of distilled water	Factor
1	1	2
1	2	3
1	3	4
1	4	5

Precaution: Reagent 22, Mg is unstable and should be kept in the dark when not in use. Change the solution at intervals of about one month.

MAGNESIA (MgO) IN WATER

Per cent and pounds per million gallons

Standard	Aliquots in ml.						
No.	1	2	3	4	5	6	7
1	.0007	.0003	.0002	.0002	.0001	.0001	.0001
	56	28	19	14	11	9	8
2	.0020	.0010	.0007	.0005	.0004	.0003	.0003
	167	84	56	42	33	28	24
3	.0033	.0017	.0011	.0008	.0007	.0006	.0005
	279	140	95	70	56	47	40
4	.0047	.0023	.0016	.0012	.0009	.0008	.0007
	391	195	130	98	78	65	56
5	.0060	.0030	.0020	.0015	.0012	.0010	.0009
	502	251	167	126	100	84	72
6	.0074	.0037	.0025	.0018	.0015	.0012	.0011
	614	307	205	154	123	102	88
7	.0087	.0043	.0029	.0022	.0017	.0014	.0012
	725	363	242	181	145	121	104
8	.0100	.0050	.0033	.0025	.0020	.0017	.0014
	837	419	279	209	167	140	120

EXPLANATION OF PLATE I

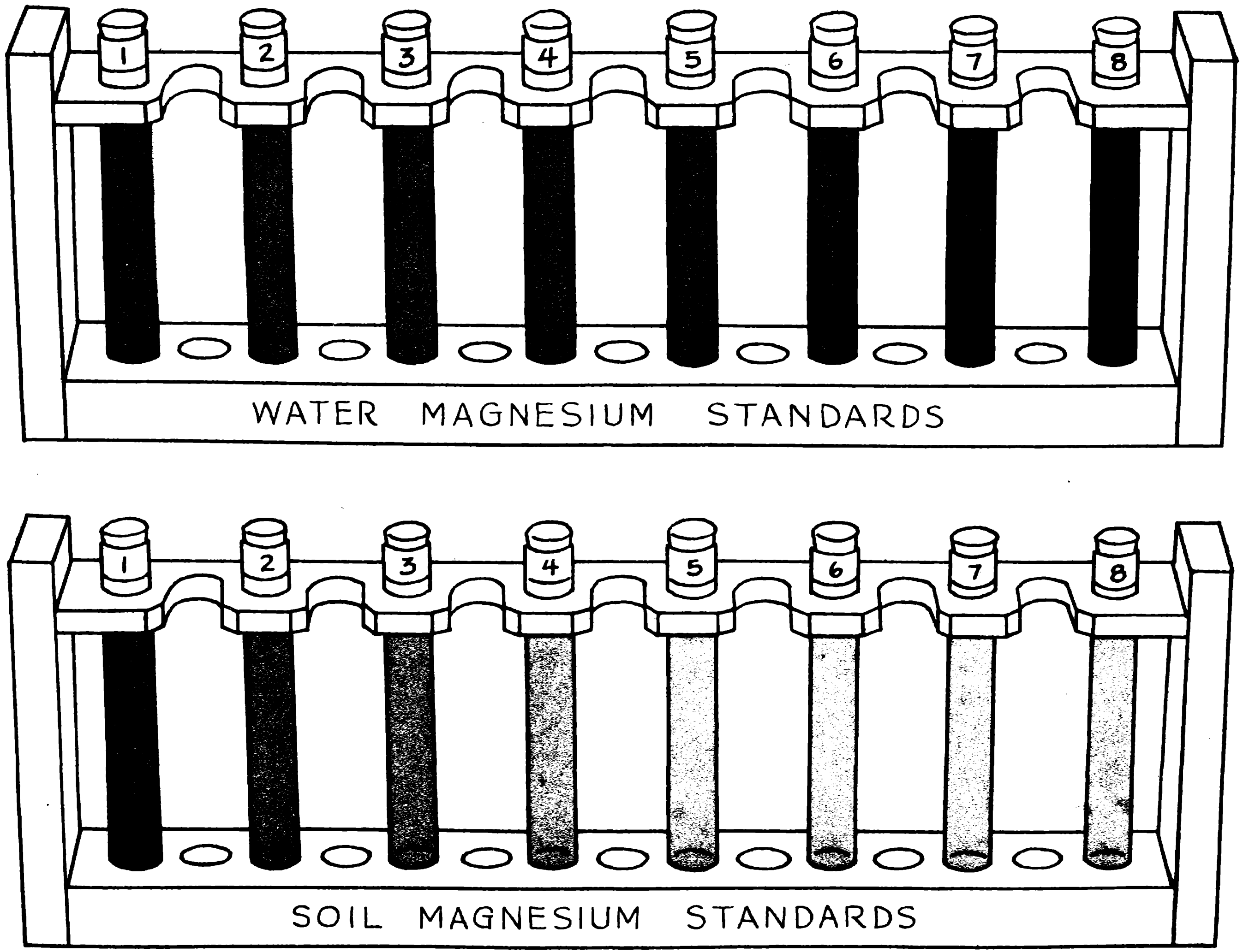
Magnesium Standards for Water Analysis

The principle followed in this set of standards is similar to other R.C.M. colorimetric detail. The tubes shown are placed in stationary positions in the rack in their sequence of color intensity. Unknown solutions in open vials are placed in the notched intervening spaces for comparison. The sealed tubes of color standards are numbered progressively from one to eight. Reference is made to a suitably prepared table for analytical values. The colored components of these standards have been prepared from mutually miscible inorganic constituents. They are chemically stable and fast to light.

Magnesium Standards for Soil Analysis

The arrangement of the standards, their coding and analytical usage are similar to those described above. At present, aniline dyes are employed as sources of color. It is necessary, therefore, to renew them occasionally.

Full details of preparation, standardization and care of standards appear in the text.


1
2
3
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8
WATER MAGNESIUM STANDARDS
1
2
3
4
5
6
7
8
SOIL MAGNESIUM STANDARDS

The Rapid Determination of Chlorides (Salt) in Water

The procedure described below for the determination of chlorides in water does not depart in any essential details from standard laboratory practice. The method has been modified so as to render it comparable to other R.C.M.

A method, previously described by Denny (1), suggested the practicability of devising a similar procedure.

Equipment Required

6 beakers, Pyrex glass, 400 ml.*
1 funnel rack, 10 hole.*
6 funnels, glass, 90 mm. dia.*
1 box Whatman No. 12, 15-cm. folded filter paper.*
1 pipette, volumetric, 10 ml.*
1 pipette, volumetric, 5 ml.*
1 graduated cylinder, 50 ml.
2 casseroles, glazed porcelain, 90 mm. dia.
2 stirring rods, 3½″ length.*
1 burette, 50 ml.*
1 pipette, special for Reagent 6, N—1 ml.*
1 gal. distilled water.*
½ pt. Reagent 26, Cl in g.s.b.
2 liters Reagent 27, Cl in 2½ liter g.s.b. (Amber bottle, or painted black on outside, leaving a narrow streak of unpainted surface.)

General Procedure

Collect one gallon of water as representative of the sample to be analyzed. Mix well and filter about 250 ml. through a Whatman No. 12, 15-cm. folded filter paper.

1. By means of a 10-ml. volumetric pipette, transfer 10 ml. of the filtered sample into a 200-ml. casserole.
2. Add 40 ml. of distilled water from a graduate.
3. Using a 1-ml. special pipette (for Reagent 6, N), add 1 ml. of Reagent 26, Cl.
4. Titrate with Reagent 27, Cl from a 50-ml. burette, stirring the solution vigorously at the same time. (Toward the end of the titration, Reagent 27, Cl should be added slowly, drop by drop, until a definite change in color results. To be able to determine the color change accurately, a blank should always be run at the beginning, using 50 ml. of distilled water, one ml. of Reagent 26, Cl and one drop of Reagent 27, Cl. This is the color to which all samples should be titrated.)
5. Read to the nearest .05 ml. the volume of Reagent 27, Cl required for titration.
6. Refer to the chart and convert the burette reading into percentage of Cl and pounds of Cl per million gallons.

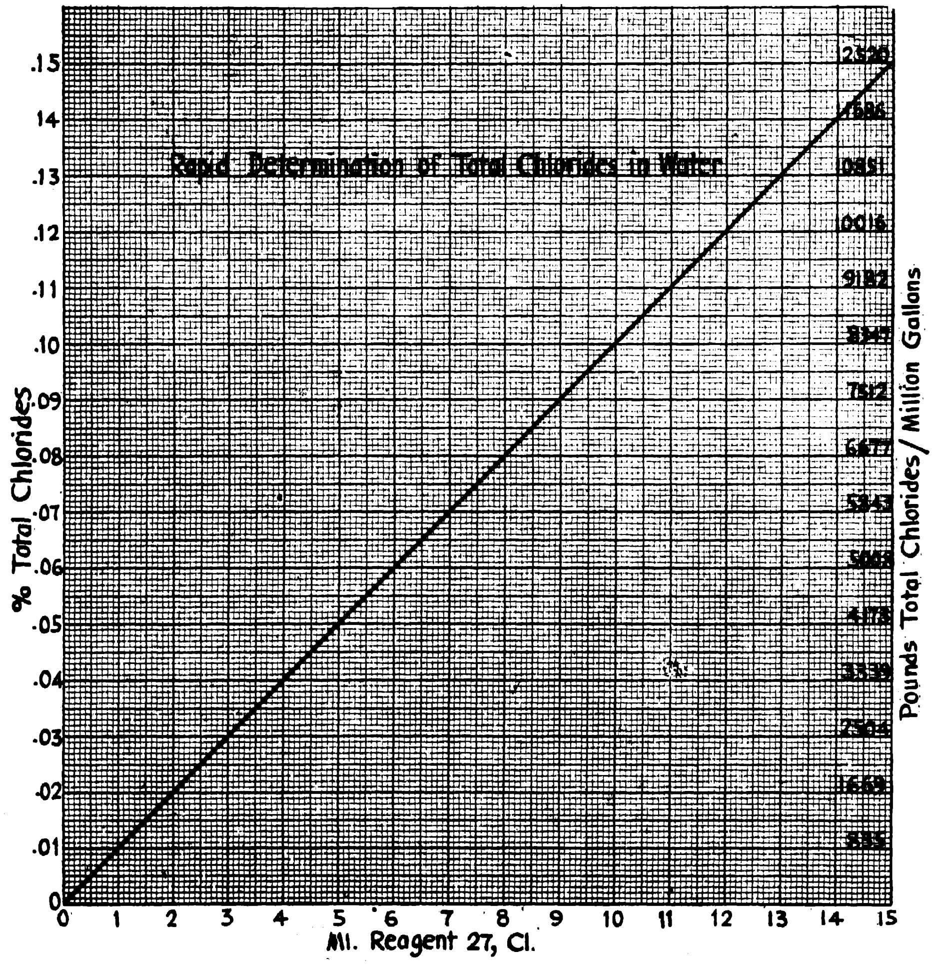
*Items included in other R.C.M. procedures.

7. A sample containing more than .15 per cent may be analyzed by taking a 5-ml. aliquot (plus 45 ml. of distilled water) and multiplying the result by 2.

8. In case a sample contains less than .02 per cent, a volume larger than 10 ml. should be taken and treated according to the following table:

ml. Aliquot*	ml. Distilled water	ml. Reagent 26, Cl	Divide result by:
20	30	1	2
30	20	1	3
40	10	1	4
50	0	1	5
100	0	2	10

9. To convert concentrations of Cl to NaCl, multiply by 1.649.



Graph for determination of total chlorides (salt) in water.

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*For the sake of accuracy, whenever possible, take a volume large enough to require at least 2 ml. of Reagent 27, Cl. A 50-ml. graduate may be used to measure aliquots greater than 20 ml.

A Refinement in the Determination of Potash in Soil Where Low Concentrations of the Nutrient Prevail

The method described below is a modification of the standard R.C.M. procedure. At the suggestion of W. W. G. Moir, Agricultural Technologist, American Factors, Ltd., the decision was reached to introduce a refinement whereby greater accuracy could be realized in estimating the potash content of soils in regions where low concentrations of the nutrient were known to prevail. The modified method was developed by P. E. Chu, Assistant Chemist, in collaboration with the author.

Additional Equipment Required

1. An extra sliding, perforated cover for the potash illuminator upon which has been mounted a 3-hole guide block 1¼″ x 3⅝″ horizontal dimensions x 2⅛″ in height. Openings in the block are made with an 11/16″ bit and are placed so that the centers coincide with similar but slightly smaller openings in the sliding cover.

2. A revised, lined chart, to be substituted in place of the one regularly used under the opal window of the illuminator. The new chart is ruled with 4 separate bands of straight lines instead of the 3 sets heretofore used. Each series differs from the one adjoining. The intensity of the bands begins with a heavy black series and recedes in 4 distinct steps to a group of faint green lines. (Refer to the previously published article for general details [2].) Illustrations of the new chart and the modified guide block slide-cover appear herein.

Procedure

In soils for which the potash content was previously recorded as "low," <.003 per cent and <75 lbs. K_2O per acre-foot, a more sensitive test has been developed, the details of which are given below. It enables the operator to analyze soils which carry as little as 20 pounds of K_2O per acre-foot. Values up to 80 pounds per acre-foot in increments not exceeding variations of 12 pounds may be determined by the same procedure.

1. Extract 7.5 grams of soil with 20 ml. of Reagent 1, K_2O as heretofore.

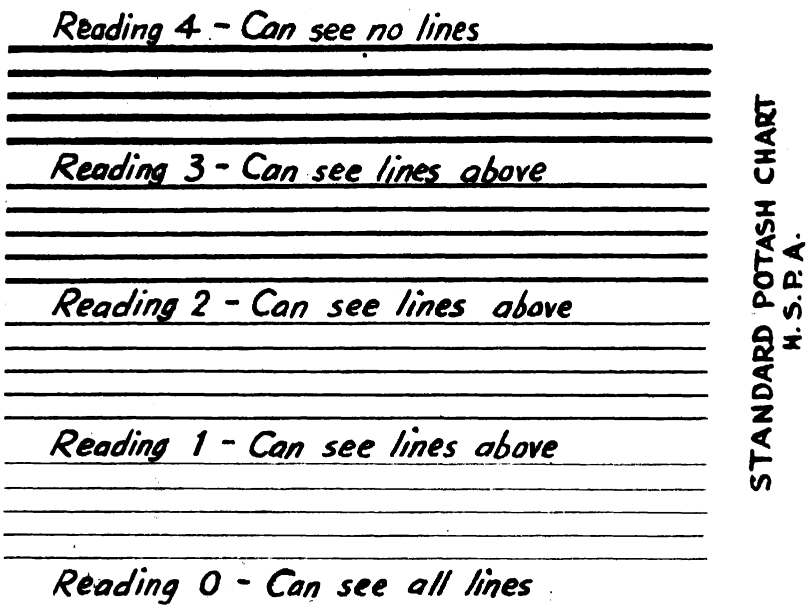
2. With a calibrated medicine dropper, transfer 1-ml. portions of the filtrate to the bottom of each of *four* vials (short-form, shell vials). It is essential to employ 4 vials in the test. If the amount of filtrate obtained is not sufficient, make duplicate extractions until the required volume is reached.

3. Add the usual amounts of Reagent 2, K_2O and Reagent 3, K_2O and proceed as directed in Steps 7, 8, 9 and 11 of the standard potash method. Use all the slots of the potash rotator.

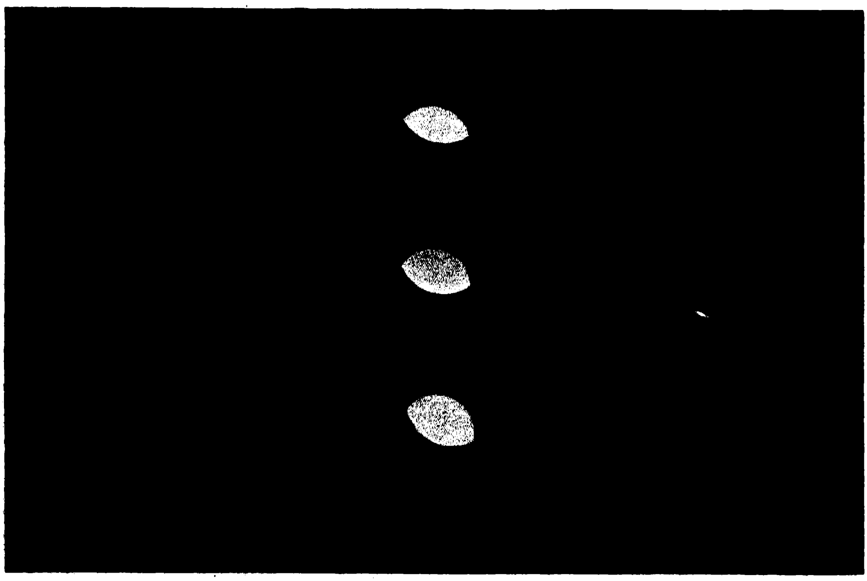
4. As soon as the rotating operation has been completed, remove the vials and, holding one of the vials in the left hand, pour the contents of the remaining three into it, letting each vial drain for 4 seconds.

5. Stopper the filled vial with the middle finger, resting its lower end on the thumb. Mix by inverting the tube 4 times in about 5 or 6 seconds.

6. Allow the vial to stand for about 30 seconds and then transfer it to the center slot of the potash illuminator.



New standard potash chart.



New slides for potash illuminators.

7. Place the openings over the heaviest lines and take readings as in the regular R.C.M. A faint set of green lines has been added to the potash chart, thereby necessitating a new reading of "0," making 5 readings in all, i.e., 4, 3, 2, 1 and 0. The reading is "0" when *all* of the lines can be seen. The other readings remain as explained in Step 13 of the standard R.C.M. procedure for potash in soil.

8. Refer to the table which follows to ascertain the percentage and pounds per acre-foot data for soils analyzed by this modified procedure. In case a reading of "0" is obtained, prepare fresh extracts, using 12½ grams of soil to 20 ml. of Reagent 1, K_2O, or 30 grams of soil to 30 ml. of Reagent 1, K_2O, as shown in the accompanying table.

DETERMINATION OF POTASH IN SOIL WHERE LOW CONCENTRATIONS OF THE NUTRIENT PREVAIL

(For high-column test solutions)

Ratio				
Gm. Soil	ml. Reag. 1, K_2O	Readings	Per cent K_2O	lb K_2O per acre-foot
30	30	0	<.0008	<20
		1	.0008	20
		2	.0010	25
		3	.0012	30
		4	>.0012	>30
12.5	20	0	<.0013	<32
		1	.0013	32
		2	.0016	40
		3	.0019	48
		4	>.0019	>48
7.5	20	0	<.0022	<55
		1	.0022	55
		2	.0027	67
		3	.0032	80
		4	>.0032	>80

The Preparation of Reagents Not Described in the Previous Article—Reagents Used in Procedures Discussed in This Paper

Cane Juice Preservative:

In a study of the composition of crusher juice or of small amounts of cane juice obtained from experiments or from the field, it is frequently necessary to put aside a series of collections for hours, or even for days, to await a favorable opportunity for the analyses.

Formalin, in these cases, cannot be made use of because of interfering chemical reactions in subsequent analytical treatment of the juice. A number of other preservatives are equally objectionable because of dilution, interference with analysis or for other reasons. Research led to the selection of a preserving mixture consisting of benzoic and salicylic acids with sodium borate. Its use, at the rate of 4 grams to one liter of juice, effectively inhibits fermentation, prevents mold formation, clarifies the juice, does not dilute it or add to its liquid volume and occasions no

objectionable side reactions with the reagents employed for the determinations of nitrogen, phosphate, and potash.

The use of the preservative in connection with the determination of nitrogen in juices suggested the possibility that, owing to clarifying action of the preserving compound, colloidal protein matter in the juice may be precipitated and thus result in finding lower nitrogen values in the final analysis. The matter was investigated by Mr. Nishimura. Using 4 different juice types from various sources at variable intervals, he determined the total nitrogen content of each fresh specimen, recorded the data and added the regular increments of preservative per unit volume of juice to each of the residues. The containers were then closed with airtight seals. At intervals, over a maximum period of about 10 weeks, he withdrew samples from each of the preserved juices and reanalyzed them. In every case the reanalysis was made on clear, screened juice, the product having become clarified within a few hours after adding the preservative. His data indicate that the nitrogen values remain unchanged, irrespective of the addition of preservative and that time and the process of clarification, apparently, exert no appreciable influence upon the accuracy or reliability of the nitrogen determination. His data follow:

	Fresh Juice		Juice Preserved by R.C.M. Compound									
Sample		% N		% N		% N		% N		% N		% N
I	4/ 3/36	.011	4/ 6/36	.0105	4/ 9/36	.010	4/11/36	.0105	4/13/36	.010		
II	4/ 7/36	.0125	4/ 8/36	.012	4/ 9/36	.013	4/11/36	.013	4/13/36	.013		
III	4/15/36	.028	4/18/36	.026	4/20/36	.027	4/22/36	.026	4/24/36	.027	6/24	.026
IV	2/19/36	.020	3/ 2/36	.019	3/ 5/36	...	3/10/36	.021	....	...	....	...

Preparation of Preservative: Weigh out 2 kilograms each of benzoic acid and salicylic acid and one kilogram of sodium borate. These materials may be either of U.S.P. or C.P. grades. Mix the powders and grind them thoroughly, using a wedgewood mortar and pestle. A preliminary grinding of the 2 acids in the mortar will facilitate subsequent incorporation of the sodium borate. The grinding operations should be conducted in an effective hood because of the irritating properties of the organic acids to the skin, but more so to their pronounced irritation of the nasal passages. Violent sneezing may be induced if this precaution is not observed.

Reagent 20, Mg:

Dissolve 0.01 gm. p-nitrobenzene azoresorcinol in 2 ml. of a one per cent NaOH solution and make the volume up to 200 ml. with distilled water.

Reagent 21, Mg:

Take 120 ml. of 50-50 sodium hydroxide solution and make the volume up to 250 ml. with distilled water, free from carbon dioxide.

Reagent 22, Mg:

Dissolve 0.15 gm. Titan Yellow in 100 ml. of a solution consisting of equal volumes of methyl alcohol and distilled water.

Reagent 23, Ca:

A solution containing 36 per cent acetic acid, C.P. in distilled water.

Normal HCl:

A solution consisting approximately of 11 parts of distilled water and one part of concentrated hydrochloric acid (by volume). Standardize by titration against 1/10 Normal NaOH.

Reagent 25, Ca: (0.04 Normal Limewater)

Place 200 grams slaked lime ($Ca[OH]_2$) in a 2½-liter glass-stoppered bottle. Add somewhat less than 2000 ml. of distilled water, free from carbon dioxide, and shake. Let stand at least 2 days with occasional agitation. Filter quickly through Whatman No. 12 filter paper (folded) and adjust to 0.04 N, using distilled water, free from CO_2.

Reagent 26, Cl:

Dissolve 5 grams potassium chromate, C.P. (K_2CrO_4) in water. Add a dilute solution of silver nitrate ($AgNO_3$) until a slight and permanent red precipitate is produced. Filter and make volume to 100 ml. with distilled water.

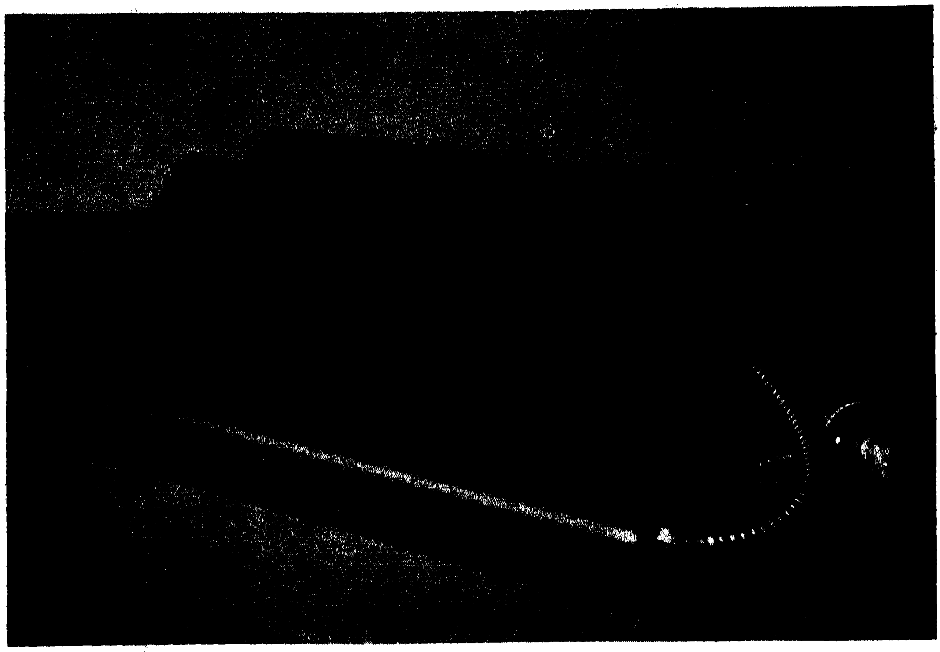
Reagent 27, Cl: (0.02819 Normal Silver Nitrate)

Dissolve 4.791 gm. silver nitrate, C.P. ($AgNO_3$) in distilled water and make volume to 1000 ml. (1 ml. = 1 mg. Cl). Check by titration against a standard solution of sodium chloride.

The Modern R.C.M. Laboratory

Elsewhere in this article there appears a building and fixture specification which may be used as a guide in the construction of an efficient and inexpensive laboratory for conducting rapid chemical analyses. The building plan and fixture detail represent the results of the study and experiences of the plantation and Experiment Station staffs of the Hawaiian sugar industry for a period in excess of 4 years.

Attention of the prospective builder is called to advantages to be gained by including in the building the cabinets, cupboards and utility table which are specified and illustrated. These furnishings permit the proper storage and care of reagents and accessories; they contribute to the neatness of the laboratory and permit the analysts to conduct their work with precision, in proper order and with a minimum of waste motion. The utility table should be mounted on casters or small rubber-tired wheels. Of still greater importance to the proficiency of chemical-analytical manipulations and to the preservation of the balance, electrical fixtures and laboratory ironware against corrosion, is the size, arrangement and efficiency of the hood. Wherever possible, select a location for the hood in a corner of the building remote from the direction of the prevailing winds. The chimney should be constructed entirely of smooth wood (under no circumstances use metal). Joints should be mitered or, preferably, dovetailed and securely fastened in place with asphaltic or similar cement. Leaks in the chimney seriously reduce the draft. The canopied cover atop the chimney should be ample to prevent the entrance of rain and roosting of birds without sacrificing the draft. The floor of the hood should consist of transite board, or other silicate cement-like material which is impervious to heat, steam and hot acid fumes. Electrical outlets from the power line or house current should terminate adjacent to,



R.C.M. electric hot plate.

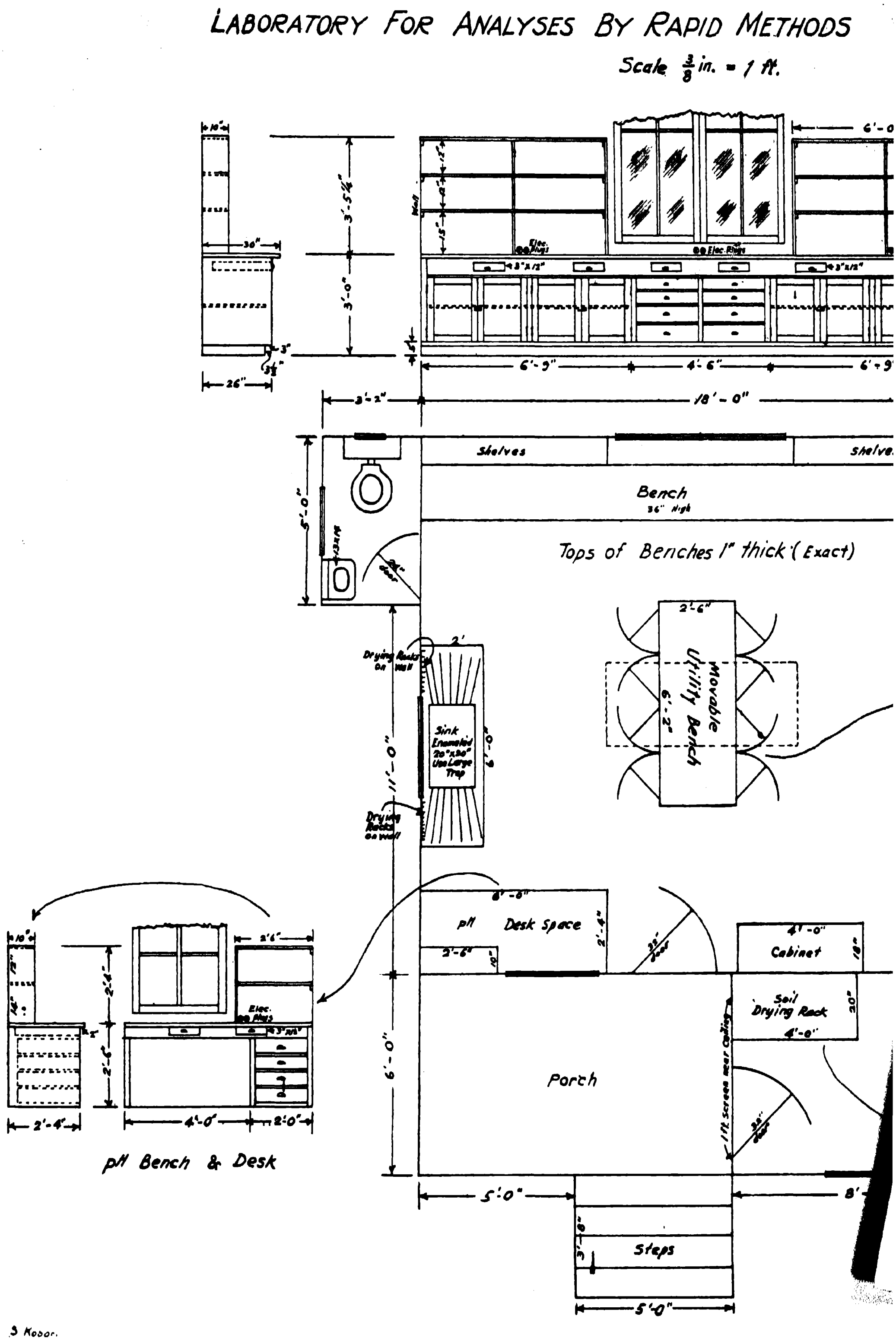
but *not* inside of the hood enclosure. The dimensions given for the hood, if followed, will insure convenient spacing of the hot plate (12″ x 24″) and several Type "H" heaters for use in nitrogen digestion work. An up-and-down sliding glass door should close the hood from the laboratory.

Photographs of several of the recently built R.C.M. laboratories are shown on pages 181 to 186.

An Electric Hot Plate Suitable For R.C.M.

Stock hot plates of conventional design and construction are not, as a rule, entirely satisfactory for R.C.M. work. This is true even of the 3-heat types which provide controllable low, medium and high temperatures. The major objection applies to the low heat. It is seldom sufficiently low.

The author prepared specifications for an electrically heated instrument, about 50 of which are now in service. The plate, illustrated herein, is a plain, rectangular, flat-top affair provided with easily accessible, replaceable, electrically insulated and fume-protected wire-wound heating elements. It operates on 110 volts. Internal electrical connections are arranged when the switch is set on "low" to produce a minimum temperature of about 80° C. and a maximum of about 103° C. in the beakers of test solution resting on the plate surface directly above the heating units. The variability in temperature limits is governed, of course, by the nature of the liquid in the containers and by the use or absence of watch glass covers. Evaporation of test solutions to complete dryness may be obtained satisfactorily without bumping, boiling or sputtering of residues as they approach a pasty condition.



Plan and fixture details for the construction of

The entire plate assembly may be obtained from the manufacturer in lots of ten for $40.00 each. Data of specifications and performance tests of this plate follow:

Dimensions: 24″ x 12″ x 4½″.
Weight: 60 pounds.
Capacity: 50 beakers of 50-ml. capacity each.
36 beakers of 100-ml. capacity each.
18 beakers of 400-ml. capacity each.
15 beakers of 600-ml. capacity each.
Heats: Three—High, medium, and low.
Line: 110 volts.
Fuse: 30 amps.

PERFORMANCE TESTS

Method I (Started and kept at "low" heat to dryness)

Material	Volume	Container	Covered or open	Max. temp. reached	Time required for evap.	Boiling, spattering, bumping
1:1 H_2SO_4	25 ml.	100-ml. beaker	Open	103° C.	....	None
N 5 Extract	25 ml.	100-ml. beaker	Open	77° C.	2 hr. 10 min.	None
N 5 Extract	25 ml.	100-ml. beaker	Covered	87° C.	....	None
Distilled water	25 ml.	100-ml. beaker	Open	77° C.	2 hr.	None
Distilled water	25 ml.	100-ml. beaker	Covered	87° C.	....	None

Method II (Started and left on "high" for 30 minutes, then turned to "low")

Material	Volume	Container	Covered or open	Initial temp.	Temperature reached in 30 min.	Time required for evap.	Boiling, spattering, bumping
Silica sand	25 ml. (40 gm.)	100-ml. beaker	Open	24° C.	152.5° C.	....	None
1:1 H_2SO_4	25 ml.	100-ml. beaker	Open	25° C.	114.5° C.	....	None
N 5 Extract	25 ml.	100-ml. beaker	Open	26.5° C.	93.5° C.	1 hr. 15 min.	None
N 5 Extract	25 ml.	100-ml. beaker	Covered	23° C.	102° C.	....	Boils
N/2 HCl Extract	10 ml.	50-ml. beaker	Open	....	....	55 min.	None

RAPID CHEMICAL METHODS ASSEMBLIES

The full complement of R.C.M. determinations includes:

1. Calcium in cane juice.
2. Nitrogen in cane juice.
3. Phosphate in cane juice.
4. Potash in cane juice.
5. Calcium in filter cake.
6. Total nitrogen in filter cake.
7. Phosphate in filter cake.
8. Total nitrogen in cane leaves.
9. Potash and phosphate in cane leaves.
10. Potash and phosphate in mill ash.
11. Calcium in molasses.
12. Total nitrogen in molasses.

13. Potash in molasses.
14. Calcium in soil.
15. Lime requirement in soil.
16. Replaceable magnesium in soil.
17. Total nitrogen in soil.
18. Available nitrogen in soil.
19. Phosphate in soil.
20. Phosphate in soils high in calcium and other carbonates.
21. Soil phosphate fixation.
22. Potash in soil.
23. Potash in soils high in calcium.
24. Soil reaction (pH).
25. Magnesium in water.
26. Nitrogen in water.
27. Phosphate in boiler water.
28. Total chlorides (salt) in irrigation and other waters.
29. Potash in water.
30. Calcium in water.
31. Potash in soil where low concentrations of the nutrient prevail.

Summary

This contribution supplements a previous article (2) describing rapid chemical methods of analysis which are applicable to agricultural-chemical studies of soils, waters, plant materials, and mill by-products.

A discussion is presented which deals with the application, preparation, use and care of durable color standards for rapid colorimetric analyses.

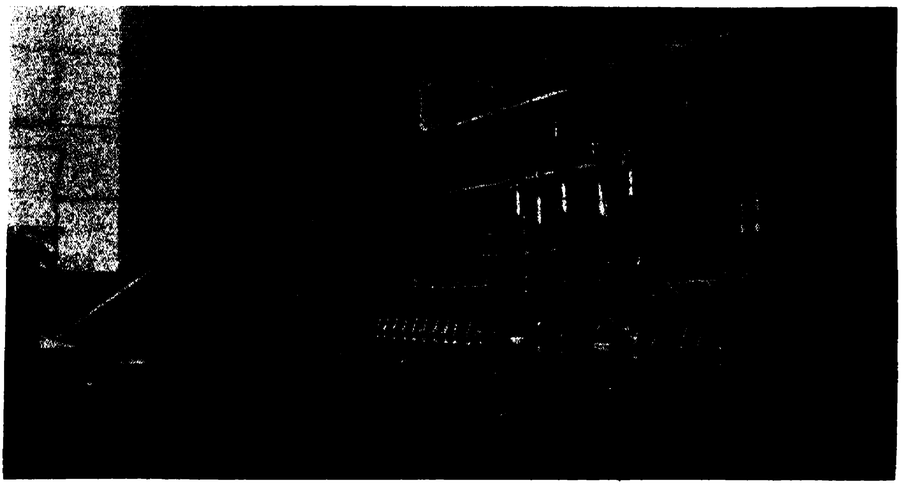
Included in this paper are descriptive details for the rapid determination of phosphate and potash in soils which carry large amounts of calcium and other carbonates. Other determinations include calcium in cane juice, lime requirement in soils, replaceable magnesium in soils, magnesium in water, total chlorides (salt) in water, calcium in water, and total nitrogen, potash, and phosphate in cane plant leaves.

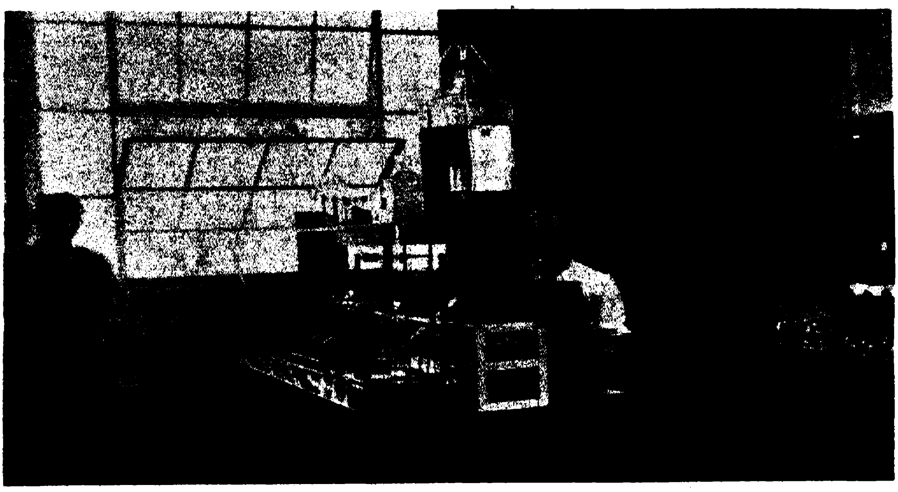
Important features of a modern laboratory are described and specifications are offered which may be used in the construction of a suitable laboratory.

Bibliography

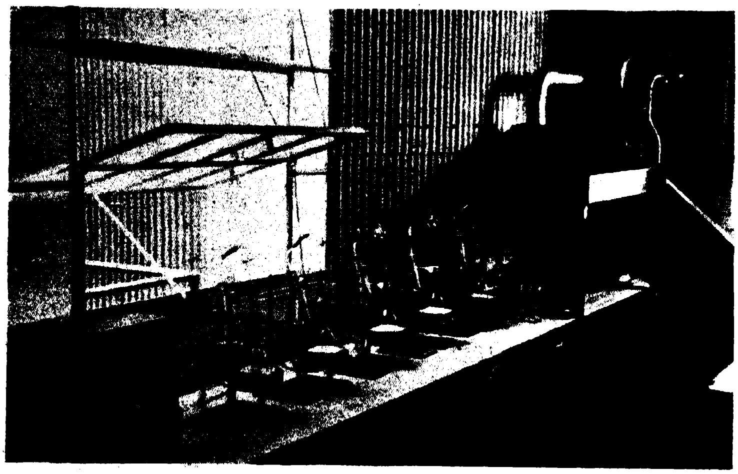
(1) Denny, F. E., 1927. Field Method for Determining the Saltiness of Brackish Water. Ecology, 8: 106-112.

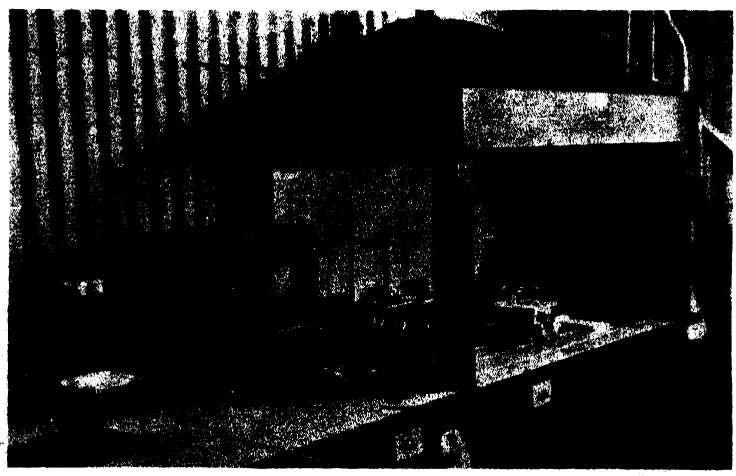
(2) Hance, F. E., 1936. Soil and Plant Material Analyses by Rapid Chemical Methods. The Hawaiian Planters' Record, 40: 189-299.



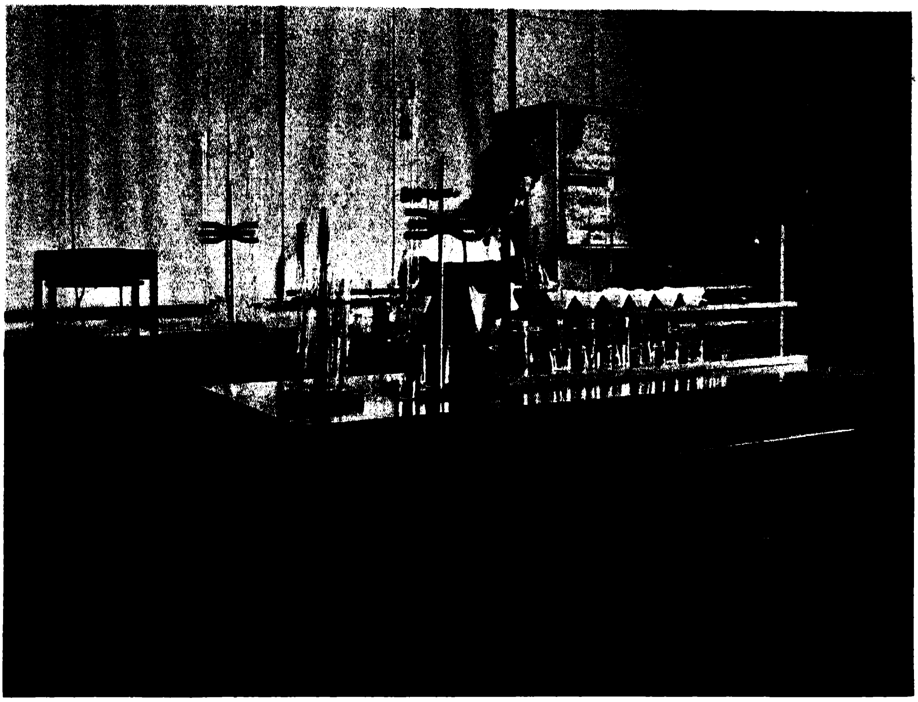


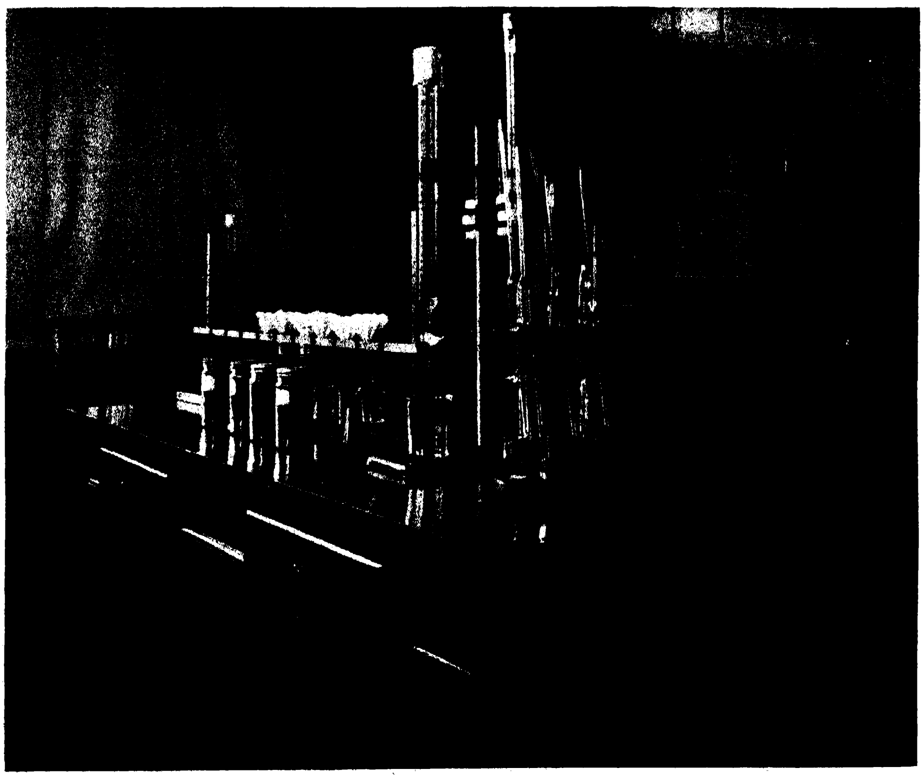
Views of R.C.M. Laboratories.
Waiakea Mill Company, Hilo, Hawaii. G. G. Richardson, Agriculturist.





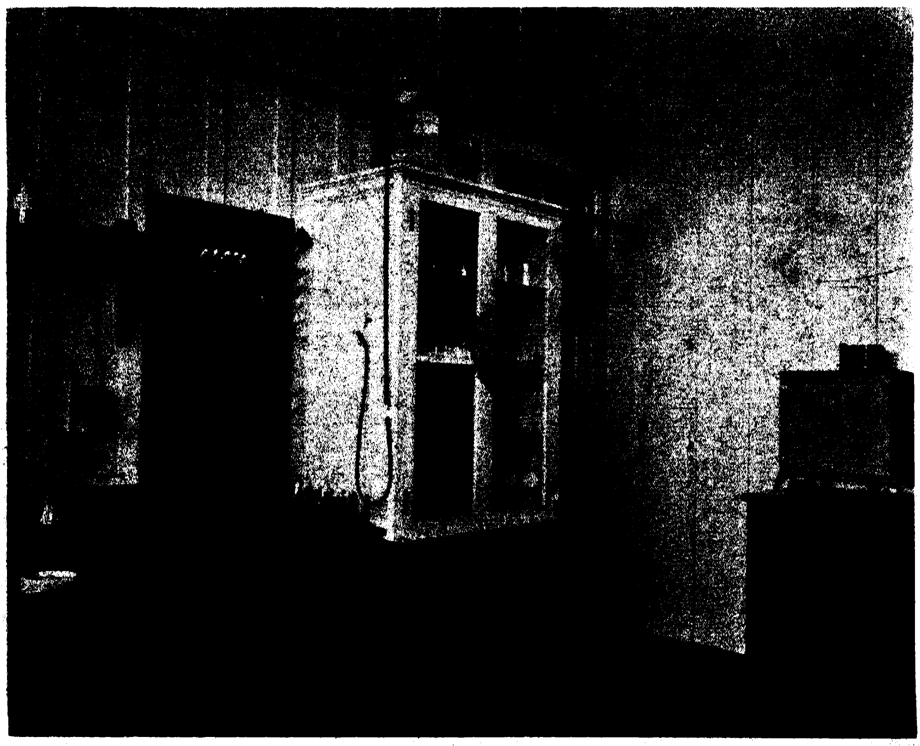
Views of R.C.M. Laboratories.
Waiakea Mill Company, Hilo, Hawaii. G. G. Richardson, Agriculturist.





Views of R.C.M. Laboratories.

Maui Agricultural Company, Ltd., Paia, Maui. A. D. Waterhouse, Agriculturist.

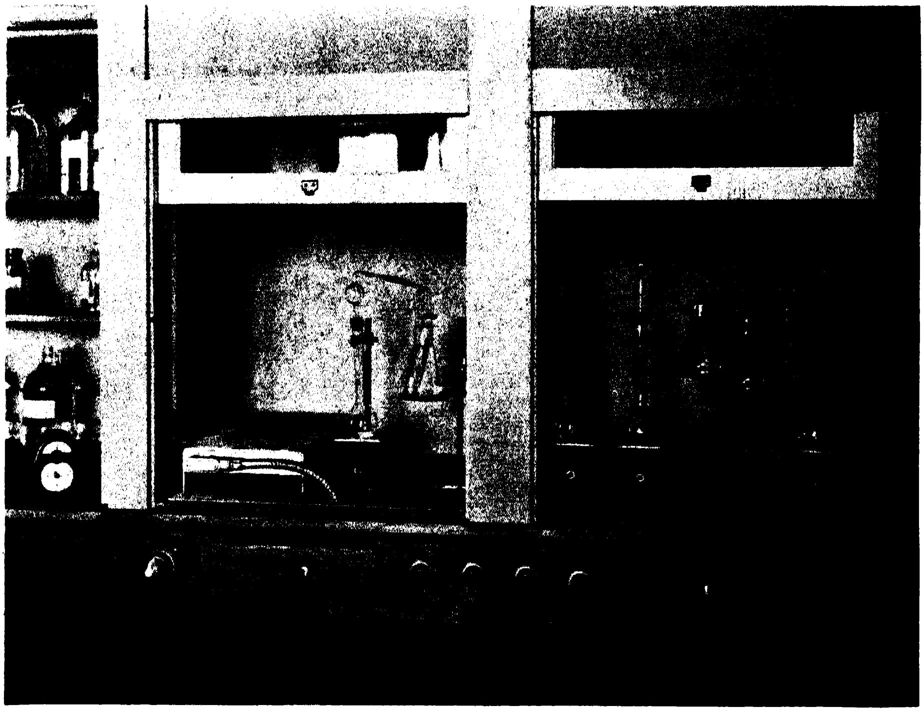


Views of R.C.M. Laboratories.

Maui Agricultural Company, Ltd., Paia, Maui. A. D. Waterhouse, Agriculturist.

Views of R.C.M. Laboratories.

Pioneer Mill Company, Ltd., Lahaina, Maui. H. J. W. Taylor, Agriculturist.



Views of R.C.M. Laboratories.

Pioneer Mill Company, Ltd., Lahaina, Maui. H. J. W. Taylor, Agriculturist.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 24, 1936, TO MARCH 15, 1937.

Date	Per Pound	Per Ton	Remarks
Dec. 24, 1936	3.80¢	$76.00	Puerto Ricos.
" 28	3.90	78.00	Cubas.
" 30	3.905	78.10	Puerto Ricos, 3.90; Cubas, 3.91.
Jan. 4, 1937	3.96	79.20	Cubas.
" 7	3.91	78.20	Cubas.
" 12	3.90	78.00	Puerto Ricos.
" 15	3.81	76.20	Cubas.
Feb. 1	3.68	73.60	Puerto Ricos.
" 2	3.65	73.00	Puerto Ricos.
" 5	3.61	72.20	Cubas.
" 19	3.50	70.00	Puerto Ricos.
" 24	3.45	69.00	Puerto Ricos.
Mar. 2	3.48	69.60	Puerto Ricos.
" 5	3.60	72.00	Puerto Ricos.
" 8	3.57	71.40	Puerto Ricos.
" 9	3.55	71.00	Philippines.
" 15	3.50	70.00	Cubas.

3-7-39

THE HAWAIIAN PLANTERS' RECORD

Vol. XLI THIRD QUARTER 1937 No. 3

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Comparative Irrigation Institutions in Hawaii and in Continental United States and Some Developments Under Them:

Although water law is usually extremely complex and a fruitful field for expensive litigation, the Hawaiian background upon which local conceptions have been built has resulted in a water code for Hawaii which is surprisingly simple and effective. Comparisons with developments in Continental United States emphasize the usefulness of the Hawaiian code under local conditions and once more focus attention upon the magnitude of irrigation developments by the sugar industry.

Scientific Irrigation Management:

We present in this issue a very complete report on scientific irrigation management. It touches on the more important contributions to the subject of plant and water relationships, with special emphasis on the more modern conceptions, particularly those of Briggs and Shantz of the United States Department of Agriculture which are supported by work of Veihmeyer and his associates in California. It is augmented with a discussion of the investigations that have been carried on in Hawaii; especially those that have come from the studies centered at the Waipio substation since 1928, which have formed the basis for establishing certain fundamental relationships for sugar cane growing on Hawaiian soils and which led to the plan to demonstrate that a sound irrigation guidance would come from the recognition and application of the basic principles involved.

After more than two years of actual usage in commercial cane fields at the Waialua Agricultural Company, Ltd., two simple tools—(1) cane growth measurements, and (2) soil moisture determinations—have demonstrated their reliability in guiding the irrigator so that he may secure the maximum cane growth with the greatest economy of water. Thus, much of the former guesswork concerned with irrigation can be eliminated.

The procedures and the results of many studies made in connection with these demonstrations are carefully described, so that the reader may, if he is interested,

duplicate the procedures and make his own interpretation of the results to convince himself of their usefulness.

Finally, the discussion concerned with the administration of plantation water offers some timely suggestions about the equipment and the organization that is needed for this efficient irrigation control, and the way in which the investigational data are used by the field men.

A very complete bibliography of the more pertinent literature is included with the report.

The Value of Irrigation Water as a Factor in Interval Control:

It is well recognized that the value of irrigation water as measured in its ability to produce sugar, varies with time of year and age of crop. Important as this conception is, particularly in time of water shortage, no concrete method of determining the positional value of water on a sugar plantation carrying fields at all ages has ever been worked out.

One possibility of doing this is presented and illustrated by hypothetical cases. How successful the scheme might be can only be determined by trial.

Comparative Irrigation Institutions in Hawaii and in Continental United States and Some Developments Under Them*

By H. A. WADSWORTH

Irrigation is a word to conjure with. Perhaps no other word in the English language is so rich in connotations. To the casual reader of romantic western novels "irrigation" immediately suggests prosperous, high-producing areas which come into being almost overnight in the heart of the desert. To the buyer of securities during the early struggles of irrigation finance and again during the expansive period of the nineteen-twenties the word too often means financial loss. The fact that such securities were often purchased under real, but perhaps indirect, encouragement by governmental agencies does not naturally correct the situation. To us in Hawaii, irrigation is a practice by which unpromising agricultural land becomes outstandingly productive, or a system of farming by which at least one of the hazards of agriculture is brought under some measure of control.

A comprehensive consideration of irrigation in all its aspects is neither possible nor desirable. But certain aspects of our local irrigation traditions are in such amazing contrast to those in Continental United States that they deserve more attention than they have received. It is of these contrasts that I would speak tonight, partly because they tend to emphasize the unique position that our irrigation institutions hold among the irrigation communities of the United States, and also because they tend to illustrate the effects of conditions upon the development of legal conceptions.

At the outset it should be recognized that irrigation is a prehistoric art in Hawaii. Both Cook and Vancouver in the accounts of their visits to Hawaii mention the terraces and canals required for the production of taro, while later adventurers, particularly Campbell and Corney, add picturesque details to the description of a practice which was already old. It would be futile and unnecessary to attempt to trace the path by which irrigation came to Hawaii. Such an attempt must await a united opinion by anthropologists as to the origin of the people themselves. But it is safe to assume that whatever their source may have been, the art of irrigation was developed to supplement food production for local consumption and not to increase real estate values nor to increase the flow of produce to remote and already adequately supplied markets.

It is a far cry from the early efforts of the taro grower to the modern achievements of the irrigation engineer in Hawaii, but the chief in prehistoric days, his konohiki and the humble taro grower have all contributed to the legal foundation upon which our modern ventures are built.

The transition from the essentially feudal organization of the early days to our modern practice is complex if detail is demanded but relatively simple in general

* Address of retiring president, Hawaiian Academy of Science, May 8, 1937.

outline. Early ventures in commercial agriculture by courageous companies, gentle but compelling pressure by mild but persuasive foreigners and the demands of other foreigners not so mild but perhaps even more persuasive conspired to bring into being an amazing series of laws and decrees which have been known as the Mahele or land division. Under the terms of these acts land titles were established. Taro growers might, and did, become owners of the tracts upon which they had labored, chiefs secured unquestioned title to larger holdings while the King and the Kingdom became owners of even greater areas. There is no place here for a detailed account of the labors of the Land Commission which heard claims and did the work necessary for the final granting of title. Let it be sufficient to say that the task was ultimately done. Boundaries were fixed, awards were granted and titles were recorded. In general, present land titles sprung from these awards.

Firmly rooted as the practice of irrigation must have been at the time of the Mahele, it is surprising that no mention of rights to use water was made in the acts themselves nor in the land awards which ultimately resulted from them. It has been tacitly assumed that an award to a certain tract of land carried rights to water as it had been used in the past. Thus, a taro grower receiving a Land Commission Award to a particular kuleana secured, by tacit consent, the right to whatever water was necessary to produce that crop. Water in excess of these claims became the property of the holder of the land award, upon which the water naturally occurred.

Unimportant as this conception may have been during the time of the Mahele, it has formed the turning point of water law in Hawaii since that time. Here, title to water is essentially as real as a land title. It may be leased or sold; it need not be used beneficially nor does lack of use destroy the right. The use of water in a particular stream is not restricted to land adjacent to it.

Active interest in the extension of irrigation facilities for the production of sugar cane began in 1856 and developments have continued at a constantly increasing tempo since that time. By 1898, when annexation by the United States was effected, the first Hamakua ditch on Maui had been completed, the Hanapepe Canal with its intricate design, was delivering water to the fertile slopes of Makaweli and Eleele and two plantations had been organized to grow cane irrigated by water pumped from below ground. It should be noted in passing that in vision, courage and resourcefulness these projects were the equals of anything in operation in the United States at the time, and they were developed under conceptions of water law which were quite unique as far as the extensive production of a crop planned for the world market was concerned.

The peculiarity of local water conceptions seems to have made a great impression upon Theodore Roosevelt in view of his campaign for conservation of natural resources. Shortly after his inauguration he sent James R. Garfield, son of the martyred President, to Hawaii to study the local situation and to recommend such changes as might seem necessary to further the national policy of conservation. The results of this survey have not been widely published but apparently no changes were advised, for none were made.

However, the apparent incompatibility of a local conception with those that had been proven excellent elsewhere provoked further inquiry by students of water law. The fact that the local code worked with the necessity of relatively little irrigation legislation seemed to be its one redeeming feature. Again in 1915 the Governor of

Hawaii apparently became skeptical of the code's soundness as a basis for the rapid extension of irrigation facilities in plantation agriculture, and appointed a committee of three, one of whom is a member of this Academy, to study the local situation and to recommend whatever changes it might see fit toward the end of bringing the local use of irrigation resources into line with common practice in the irrigated West. With considerable wisdom this committee engaged the services of A. E. Chandler, a member of the Public Utilities Commission of California and a water-law attorney of note, to study the situation with its local background and to recommend whatever changes in water administration seemed advisable. Mr. Chandler's report is amazingly brief and recommended no changes. None were made. Here, privately owned water may be considered as real property, title being vested in an individual, or his assigns, and subject to no more governmental scrutiny than any other class of property.

As our local conceptions of water law are the results of early practices, modified as times have changed, so water law in the irrigated West is a composite of early practices, as modified by basic principles of English common law and certain more applicable doctrines of Spanish and Mexican origin. But there the picture is much more complex.

Irrigation came late into the life of the American people. Normal rainfall is adequate for field and orchard crops east of the 100th meridian and seventy-five years were to pass between the beginning of our national life and the significant invasion of this great American Desert, as the region beyond the 100th meridian was known. Conceptions of property rights, some of local origin and some lifted bodily from the Common Law of England, were firmly established before this western migration began. It is only natural that the emigrants carried these conceptions with them. Nor is it surprising that doctrines established in England and found satisfactory in our well-watered eastern seaboard, where the principal duty of streams was to float ships and to operate water wheels, failed to be applicable in the irrigated West. But before this incompatibility had been noted, these doctrines had been incorporated in the laws of many of the Western States.

The situation was still further complicated by the concurrent advent of settlers with backgrounds entirely different from those of the miners and adventurers who had followed the gold trail from the East and Middle West and who had failed to return. These people moving north from Mexico through the Southwest and into California came from an area in which irrigation was and always had been a vital factor in agriculture. To them the waters of their rivers had but little value when allowed to run in their natural channels. To produce wealth, water had to be diverted; it had to be spread over the sun-soaked plains for the production of crops—a procedure which was highly profitable to the diverter but distressing to a potential irrigator along the lower reaches of the stream. For the protection of all concerned such waters were appropriated by ceremonies which have become increasingly formal as waters have become of greater value. Newcomers were made to realize that water could only be available when all prior appropriators had been satisfied, but that prior appropriations might be declared void if no beneficial use was being made of the water diverted.

Such conceptions had proven valuable and adequate in Mexico for many years. Naturally they were carried into the United States and under the aggressive heads

of the newly organized States and Territories of the West, the adjudication of waters in natural streams became a function of the State and Territorial governments. The State became the granter of appropriative rights; the State determined when beneficial use of water had degenerated into non-beneficial use; the State courts ruled in cases involving priorities of use. In spite of the basic application of these conceptions to the use of water in irrigation as compared with the use of flowing water as a source of power, it is evident that they might open the way to almost endless litigation. And indeed they have done so. It is empty comfort to recall that contentions over water rights are as old as man's interest in irrigation. It is said that the English word "rivals" finds its derivation in the Latin "rivus," meaning small stream or ditch. Apparently users of water from the same stream were rivals, in the early use of the word.

Aside from the troublesome details of priority and beneficial use which have been sufficient to flood the court calendars in many Western States, there has always been the possibility of a direct conflict of these conceptions with those of English common law which in some States is the basis of Constitutional rights. The doctrine of riparian rights is dear to the heart of the staunch supporter of English common law. This doctrine, important enough in industrial communities but quite inapplicable in a region in which irrigation is important, holds in general that the natural flows of streams may not be modified by diversions nor by the installation of regulatory dams nor may the waters of the stream be contaminated nor polluted in their passage on their natural course.

Several of the Western States recognized the incompatibility of these two basic conceptions early in their judicial history and rejected the riparian doctrine at the outset, or very early. Others, notably California, clung to it through much costly litigation, the proponents of the riparian principle usually losing ground with each decision.

In 1928 a constitutional amendment was adopted in California which demanded reasonable use from riparian landowners, a condition which apparently runs counter to the doctrine itself. But the necessity of some such limitation is apparent from the history and decision in Herminghaus et al. vs. Southern California Edison Company. In this case the court held that a storage dam, high in the Sierra Nevada Mountains, so controlled the flow of the San Joaquin River that rights of riparian landowners below the dam had been violated. The fact that the riparian landowner involved profited by unregulated stream flow only through the occasional flooding of 18,000 acres of unimproved pasture land seemed sufficient cause, under the doctrine of riparian rights, to delay and financially handicap a great project which had the control of flood waters as one of its ends. It is very doubtful if this decision together with the constitutional amendment which it prompted has quieted the inevitable conflict between such incompatible conceptions.

It is in this atmosphere of conflicting doctrines, of reversed court decisions, costly litigation and judicial delay that American irrigation institutions are founded. The basic law naturally varies in each of the Western States and of course each State makes it own interpretation. Regardless of such variations however, one conception is common to them all, that is that water is the property of the State. Individual use is by permission from the State, such permission being subject to denial or to withdrawal unless certain specified and rigorous conditions are complied with.

By way of contrast one turns again to Hawaii. Here, as has been stated, water is ordinarily considered as real property subject to all privileges of rental, lease or sale. It is a personal asset of recognized worth, as is indicated by the paucity of title transfers.

It is far afield from the purpose of this discussion to debate the social justice behind these two entirely different conceptions of water administration. Both are natural developments of early doctrines which have been modified and strengthened as time and occasion demanded. The point is that our simpler scheme in Hawaii has been surprisingly effective under conditions as they exist here. And in the opinion of at least two of those well qualified to judge, no contingency is conceivable in which the local code will be inadequate.

The methods by which irrigation developments were promoted and financed in Hawaii and in Continental United States are as different as the legal conceptions which permitted them. Here a single, valuable crop with a sure market was to be provided with water. Sugar prices were fairly constant and, except for one or two distressing periods, high enough to encourage ventures into lands too dry to permit cane production without irrigation. Here, until very recently, a sure and open market was available for as much sugar as could be produced. It is true that the market was far from Honolulu in miles but the costs involved were known and the value of the crop at the market was subject to close prediction. Hawaii is once more unique in its background as an irrigated community. Ordinarily considerable trial and error is necessary to determine profitable crops in a newly irrigated area. And too often the natural market for such crops is not only far away in miles but subject to seasonal flooding from other communities with the same ability to produce and with perhaps lower delivery costs. No such difficulties faced the pioneers in Hawaiian irrigation. Here the problem has been to acquire the right to use water, to lead that water to suitable cane land and to devise means of distribution. Such problems are those of the irrigation engineer. They are tangible; they lend themselves to definite solution; they are free from those aspects which so dominate the activities of such agencies as the United States Reclamation Service, perhaps the greatest group of irrigation engineers in the world. Of greatest importance, however, is the fact that in Hawaii the development and use of water followed a need for that water rather than the anticipation of such a need. Here new developments have been financed from the profits of the old; but most significant is the fact that local ventures have not received governmental subsidy in any form. To be contrasted with this practical and extremely utilitarian philosophy is that of the Federal Government and most of the Western States. Due to social implications which have found little manifestation as yet in Hawaii, irrigation in Continental United States has demanded and received encouragement, advice, and financial support by Federal and State agencies in almost unbelievable measure.

Early irrigation enterprises were informal, effective, as far as the actual production of crops was concerned, and ordinarily not particularly costly. But as has been noted elsewhere, new projects had the characteristic of being more expensive than those that had preceded them. Easy diversions invited early effort, and natural dam sites, particularly those demanding only modest investment, were soon utilized by the private and aggressive irrigation pioneer. This phase was soon over, however.

In the meantime the Federal Government had embarked upon a general plan of settling the arid West. By the middle of the 19th century the humid lands of the Mississippi Valley had been superficially occupied and a stream of adventurous souls, looking for land rather than gold, moved westward across the 100th meridian and into an area where irrigation is essential to successful farming.

It is not for us to question the policy of the Federal Government which resulted in the extension of irrigation facilities over this great region. Great tracts of Government land in Western States were ceded to the States with the understanding that the States provide irrigation facilities and resell to actual settlers at the cost of the improvements. A separate bureau in the Department of the Interior was established to provide water for Government land set aside as Reclamation Projects, the thought being that land so improved could be readily sold to new settlers in the districts and that the carefully amortized payments could be made by the settler from profits from the land. It should be said in passing that some of our mightiest engineering achievements have been made under the direction of the Bureau of Reclamation. Even the poor Indian, crowded into reservations particularly in the Southwest, felt the effect of this expansive interest of government in irrigation development. Projects were developed on the reservations with the thought that these wards of the Government might share in the rewards which were to flow from the irrigation in the West.

Without prejudice it must be admitted that the projects have not been entirely successful. It is still true that irrigation is essential for consistent crop production west of the 100th meridian, but it is also true that more is required than a beautifully designed storage dam in the mountains and an intricate system of canals to turn every casual applicant for land into a prosperous and successful farmer. Moreover, there did not seem to be the demand for irrigable land that had been anticipated.

Certain social and economic aspects of the picture had apparently been ignored. Distances to consuming centers were often great in view of the remoteness of some of the projects and transportation costly, particularly during their early struggles. Even more important as a factor in the ultimate success or failure were the limited personal resources of the settlers to whom allotments were granted. Magnificent irrigation structures resulting in bountiful water supplies to arid land do not always spell success in irrigation ventures. It has been said that, on the average, the present holder of one of the allotments is the third in a series. If this be true the successful settler starts, not with bare land, but with a homesite enriched by the capital and efforts of his two predecessors. The steps taken by the late Dr. Elwood Mead to correct this situation and to allow for the inevitable social complications which must develop, is one of the brightest chapters in the history of American reclamation.

Nor had the States remained idle. Legislation providing for the formation of irrigation districts was enacted by each of the Western States. Under such authority unirrigated areas might declare themselves irrigation districts after a specified type of referendum, and by so doing make it possible to bond the district for the purpose of providing irrigation facilities. Being political subdivisions of the States, money for interest and sinking fund was collectible through the ordinary tax collecting machinery of the county. Of greater importance is the fact that such irrigation district bonds acquired a dignity often out of keeping with the real security

behind them. Being bonds of political subdivisions of States they usually became legal investments for savings banks. Once more we note the fine touch of governmental subsidy of irrigation ventures. The fact that in this case the subsidy lies only in the extension of governmental credit does not make it any less real. One should be quick to note the safeguards established by the States in this regard. Every proposed district needed the approval of the State engineer before its formation was permitted. And in many cases the recommendation of this official as to engineering feasibility was seconded by one assuring economic and social feasibility. The fact remains, however, that such recommendations made during a period of agricultural expansion and rising prices may prove disastrous at another part of the cycle. Irrigation district finance is a long-time project.

We have then in western United States a long catalogue of irrigation institutions. Some types of organization are out-and-out wards of the Federal Government. Here Government land is provided with irrigation facilities not because of any immediate necessity for increased crop production but because the settlement of that land is patently desirable and settlement is impossible without irrigation. In another class of organization the initiative comes from the landowners themselves, who in a carefully qualified election, move to bond their land for irrigation improvement. A cynic might wonder how many votes in such an election were won by the thought of increased production and better living conditions, and how many votes were won by the thought of appreciated land values by the proposed irrigation facilities with the possibility of moving out of the district to residence in the county seat.

The irrigation census of the United States, published in conjunction with every general census since the eleventh, gives statistical evidence as to the extension of irrigation facilities in the nineteen Western States by enterprises of these many kinds. In 1889, three and one-half million acres were irrigated. By 1899 the area had doubled. At the time of the thirteenth census this geometric increase was once more in evidence, some 14 million acres being reported as irrigated in 1910. In 1929, this area had increased to 19 million acres. Essentially the same irrigated area was reported in 1930. How much of this rapid falling-off in the rate of irrigation extension in the United States may be charged to the ever-increasing costs of new projects, how much to the inevitable balance between supply and demand, and how much to social and economic implications would form a nice study for one interested in irrigation economics.

We have no corresponding figures for the rate of irrigation development in Hawaii. In fact no compilation of figures relating to areas irrigated was made until 1935. At that time 128,000 acres were reported, or about 0.7 of one per cent of those supplied with water in the States.

In Hawaii we are apt to confuse the words "irrigated" and "irrigable." Irrigated land of course means land which is actually being supplied with water for crop production, while "irrigable" is used to mean land which might be served with water with existing facilities if such land were to be put under crops. With these definitions it is evident that all irrigable land is irrigated in Hawaii, but this is certainly not so in Continental United States. There, the slow rates of settlement of some projects have been a matter of some concern. A scrutiny of figures given in the most recent census indicates that about half the lands of the average irrigation project are actually irrigated in the first 10 to 15 years of its existence, but that the

reclamation of the second half is much slower. The curve for 1930 indicates that a three-fourth development may not be expected before 70 years have passed. The corresponding statement for Hawaii would indicate complete development of irrigable land within the first year.

Other figures culled from the census of 1930 and from local reports of varying origin provide other interesting comparisons. For example, 36 per cent of Hawaii's cropped area is irrigated as compared with 8 per cent for the nineteen Western States. Only four States of the group—Kansas, the two Dakotas, and Oklahoma—irrigate less land than Hawaii in terms of acres, but only seven of those States have spent more money in irrigation development than has Hawaii. From this it follows that it must cost more to provide irrigation facilities for Hawaii than on the Mainland, and indeed it does. By 1935, Hawaii had spent $304 per acre to provide irrigation facilities for its average irrigated acre, a figure which is to be compared with $89 for Arizona, $66 for California, and $64 for Washington, these States standing at the top of the list when arranged in the order of decreasing investment per irrigable area.

Still more spectacular is the comparison between the values of the irrigated crops. In Hawaii the value of the crop from the average irrigated acre was $340 in 1935. The corresponding figure for Washington in 1929 was $151 and for California, $126. From such figures we may derive another comparison with a much more imposing title. This is "irrigated crop income per dollar in water development for each acre irrigated." For Hawaii this figure was $1.11 as compared with $0.87 for the nineteen States. In other words, a dollar per acre invested in irrigation works in Hawaii has resulted in an annual crop income of more than $1.00 per acre as compared with 87 cents for the average enterprises on the Mainland.

It would be folly to suggest that our unique water laws and our local irrigation institutions are responsible for any such record of achievement. Our fertile soils, abundant sunlight, aggressive management and a secure market for a valuable crop have all contributed to the local picture. But the comparison, unrecognized as it may be by Mainland authorities in irrigation administration, still stands.

Alone and unencouraged by Governmental help or subsidy, basing costly ventures upon new and untried water law, believing that irrigation is primarily an aid to crop production rather than a tool to be used toward the end of social progress, our irrigation pioneers have put Hawaii in a place unique in the annals of irrigation. The fact that local achievements in this outpost of American agriculture have so far escaped recognition need not detract from our appreciation of their soundness.

Scientific Irrigation Management

A REVIEW OF INVESTIGATIONS ON PLANT AND WATER RELATIONS

THE WAIALUA IRRIGATION INVESTIGATIONS

THE ADMINISTRATION OF PLANTATION IRRIGATION WATER

By H. R. SHAW AND J. A. SWEZEY

CONTENTS

FOREWORD

Studies on the interrelation of soil moisture, weather, and crop production reported in the following series of papers are the result of eight years of investigation by the Experiment Station of the Hawaiian Sugar Planters' Association.

The reports cover briefly previous work in Europe, the mainland United States, and in Hawaii on soil moisture as related to plant growth, and describe the steps leading toward the modern conception of plant and water relationships. They touch on fundamental investigations conducted since 1928 at the Makiki station, the Waipio substation, and various plantations of this Association in determining certain basic denominators between the soils of Hawaiian cane lands and the growth and development of the sugar cane plant as affected by soil water.

The reports describe in some detail a cooperative investigation by the Waialua Agricultural Company, Ltd., and the Experiment Station of the H.S.P.A. in which the culminated evidence gained from earlier studies under controlled conditions was applied to commercial cane fields in an endeavor to gain a more efficient use of irrigation water.

The present reports do not purport to be a series of scientific monographs nor an exhaustive analysis of the complex relationships between plant growth, soil moisture, and weather. They will, we hope, provide a guide to the practical application of scientific principles in plantation irrigation and may stimulate further investigation and study of an interesting and important subject.

Some of the material presented has been published previously by one or both of the writers in *The Hawaiian Planters' Record,* in *Proceedings of the Association of Hawaiian Sugar Technologists,* and in mimeographed reports to the plantation members of the Hawaiian Sugar Planters' Association. We have endeavored, in this series of reports, to organize in convenient form the major contributions of workers in Hawaii to the problem of plant and water relations.

We are indebted to many individuals for helpful suggestions and active interest in various phases of the investigations reported here. Prof. H. A. Wadsworth, of the University of Hawaii, is largely responsible for introducing to the Hawaiian Islands the modern philosophy of soil moisture movement and availability, and has been generous in his advice and active participation in all phases of the project. H. P. Agee, Director of the Experiment Station at the time the project was organized, has stimulated the development of the investigations by his suggestions and scientific curiosity. Dr. H. L. Lyon, present Director of the Experiment Station, and R. J. Borden, Agriculturist, have contributed much in energy and sympathy to the project. The accuracy and patience of Y. Matsusaka, who conducted the tests on the wilting percentages of plantation soils, added largely to the valuable results of this work.

Our thanks are also due to F. C. Denison and many others of the Experiment Station staff, to the agriculturists and field staffs of the plantations who contributed to the work, and particularly to J. H. Midkiff, C. B. Butchart, and the staff of division overseers of the Waialua Agricultural Company who have aided the progress of the investigations by their cooperation and interest. Finally, we wish to thank the assistants who, by their loyal devotion in laboratory and field, have provided the basic data described in these reports.

A REVIEW OF INVESTIGATIONS ON PLANT AND WATER RELATIONS

By H. R. Shaw*

The history of irrigation is nearly as old as the history of agriculture itself. Traces of irrigation systems used by forgotten civilizations in Asia, Africa, South America, and southwestern United States indicate that the craft of irrigation is well over 3,000 years old. Irrigation as a science, however, is one of the newer contribu-

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tions to the field of agriculture. The modern conception of the relationship between the soil, plants, and water has existed barely 30 years.

Inevitably, in a new and growing field of investigation, a maze of conflicting theories, hypotheses, and fallacies has arisen to add complexities to an already complex subject. The very fact that various investigators differ so widely in their interpretations of the response of the plant to water, and the fact that the viewpoint toward soil moisture investigations has constantly changed during the past fifty years should be sufficient indication that the results of previous work must be accepted with caution. Even greater deliberation must be made in any attempt to apply the findings of Mainland and European workers to our local conditions. It must be admitted, however, that a background of previous investigations is both desirable and necessary for an intelligent prosecution of any problem.

This paper will attempt to present briefly the major contributions of the past as a foundation to the steps leading toward the best modern thought on plant and water relations. While the paper makes no pretense of being an exhaustive study of research in plant physiology and soil physics for the past century, it should provide some basis for further study by those interested and will serve to indicate the trends and progress of irrigation investigations.

To aid readability, direct citations to the literature are not used in the text. The writer is particularly indebted to N. A. Maximov's excellent book, *The Plant in Relation to Water*, as a source of information on the work of European investigators. A selected list of reference abstracts on the major contributions of American and British workers since 1900 is appended to the report.

Investigations Prior to 1900

Until the present century the absorption and use of water by plants was almost entirely a study by botanists and physiologists. During this period (roughly from 1850 to 1900) in which most of the investigations were conducted in Europe under Pfeffer, Sachs, Vesque, and others, the plant was studied under artificial laboratory conditions in order to observe osmosis and osmotic pressures, root absorption, and other fundamental relationships of the plant and its environment. Valuable as the results of these investigations were in establishing the basic physiological reactions between the plant and water, they left much to be developed in applying the findings to plants in the field.

Sachs, working with tobacco plants in 1859, was apparently one of the first investigators to recognize the relation of plant wilting to moisture inadequacy as a possible function of the soil type. He determined the maximum amount of water which could be held by three different soil types as well as the residual moisture in each soil at the time tobacco plants wilted in a humid atmosphere.

Gain, in 1895, and Hedgecock in 1902, undertaking ecological studies of plants in their relationship to arid and humid regions, apparently found that plants differ in their ability to take water from the soil.

In soil physics, as well as in plant physiology, the tendency was to study reactions under artificial rather than natural conditions. Hence, many of the early investigators used rubber balls, glass spheres, and similar means to illustrate and study the effect of surface tension, capillarity, and other soil and water phenomena. That

many of the principles do not hold when applied to natural soils, and particularly to colloidal soils, has been demonstrated frequently since that time.

Investigations Since 1900

Relation of Plant to Soil Moisture:

It was not until the present century, with the wide development of irrigation and reclamation projects in the western United States focussing attention on the importance of adequate moisture supply, that the study of plant and water relations became a practical as well as an academic field of investigation. Investigations of the past thirty years have been more directly concerned with soil moisture conditions in the field and with the study of crop responses as indicated by the plant itself.

The popular conception of thirty years ago, and one which is still widely accepted in some quarters, is that there is an "optimum" moisture content for each soil type at which a given plant species will obtain maximum growth. This optimum moisture content, which supposedly varies not only with the soil type but with the type of plant grown, apparently cannot be defined in terms of any physical property of the soil nor with the physiological condition of the plant. Cameron and Gallagher in 1908 recognized the "optimum" moisture content, but suggested that it might be a range of moisture content within which the plant might grow equally well. They also made the very important suggestion, based on their experimental results, that this zone of equally available soil moisture might be a physical function of the soil rather than a purely physiological function of the plant.

It remained for Briggs and Shantz, of the United States Department of Agriculture, to publish in 1911 the results of extensive investigations which did much to change the conception of the moisture relations of plants. These investigators studied hundreds of plants of various species in many types of soil. The plants were grown in containers holding a small mass of soil and were so sealed that the only losses of moisture resulted from transpiration through the plant. The residual moisture content of the soil at the time the plant wilted to such an extent that the leaves could not regain turgidity after being placed in a dark humid atmosphere was determined for each of the plants at different stages of its development, under different environmental conditions, and in different soil types.

The results of the Briggs and Shantz investigations indicated that all plants (regardless of age, species, or environment), when grown in the same soil wilted at approximately the same moisture content. On the other hand, the soil moisture content at the time the plant wilted differed widely among different soils, and ranged from extremely low values in sandy soils to comparatively high moisture contents in clay loams.

Such a conception of plant and water relationships as that advanced by Briggs and Shantz was so contrary to general opinion that it was only natural that their results were received with some degree of skepticism both by scientists and by farmers. As has been indicated previously, earlier investigations by other scientists, notably Sachs, Hedgecock, and Gain, indicated that different plants do not avail themselves equally of soil moisture although Maximov points out that these investigators studied plants grown in open porous flower pots in which moisture was probably lost by direct evaporation from the soil surface as well as through the

porous walls of the container. Such a condition would result in unequal drying of the soil, which may have influenced the results.

Exceptions to the Briggs and Shantz theory of a constant wilting point for all plants grown in a given soil type have been made by many plant physiologists, particularly by those associated with the Desert Laboratory at Tucson, Arizona. The general objection by these workers was that the environment in which the plant is grown has a major influence in causing the plant to wilt.

Undoubtedly a distinction must be drawn between temporary and permanent wilting. Temporary wilt may be defined as that stage in which the demand of the plant for water is greater than the power of the roots to supply it or of the plant tissue to transport it from the roots to the region of threatened deficiency. Such a condition would exist when the factors inducing transpiration are so high that the rate of moisture depletion from the plant leaves is greater than the rate of moisture absorption from the soil by the plant roots. At such a stage leaves would lose their turgor, and growth would cease temporarily until the intensity of climatic factors was lowered so that the rate of supply would again equal the rate of demand.

Permanent wilting, on the other hand, is that stage at which leaves will not regain their turgor even under greatly reduced demands by transpiration. Consequently, complete turgor cannot be restored and growth will not be resumed until additional moisture is added to the soil. Thus, the major influence causing temporary wilt is the climatic factors over which we have little if any control; the major influence causing permanent wilting is the amount of soil moisture available for growth. Over this factor we may exert a very definite control.

Brown, in an investigation conducted at the Desert Laboratory, found that the residual moisture in the soil at the time various plants wilted was apparently influenced by the environment in which they grew. Plants grown in small pots under direct sunlight wilted at a higher moisture content than plants of the same species grown in a humid room. Brown apparently did not distinguish between temporary wilt and permanent wilt which was defined by Briggs and Shantz as the state at which the leaves could not regain turgidity after being placed in a dark humid atmosphere. Brown felt, however, that his results were not incompatible with those of Briggs and Shantz since he stated, "The results of Briggs and Shantz are applicable, providing that wilting occurred under the same general environmental complex under which the plants have been grown."

Caldwell, working at the same station, states that the residual soil moisture at permanent wilting of a plant varies not only with the environmental conditions but with varying evaporation rates of the atmosphere. This investigator endeavored to distinguish at what hour of the day plants first enter the wilting state. In studies conducted in a dry, hot atmosphere where transpiration losses are great, and with the determination of wilting based on ocular judgment, this degree of refinement would appear to demand powers of observation beyond the ordinary.

Shive and Livingston seem to find that the age and development of the plant was not an important factor in the degree of soil moisture depletion, but that the soil moisture content at permanent wilting varied with the intensity of evaporation. It should be observed that all three investigations mentioned above were conducted at the Desert Laboratory in Arizona. It would appear probable that the environmental

factors under which the experiments were conducted might be considered as an extreme so far as excessive transpiration and evaporation rates are concerned, although the authors mentioned made some attempt at artificial control of light intensity.

More recent investigations in California and the Middle West tend to support the theory of Briggs and Shantz that all plants grown in a given soil undergo permanent wilting at approximately the same soil moisture content. Veihmeyer and his colleagues in California studied the growth and wilting characteristics of annual plants and fruit trees in small containers, in large tanks weighing over 2,000 pounds, and in the field. They substantiated the major premise of Briggs and Shantz in finding that the permanent wilting percentage is fundamentally a function of the soil type. These workers also improved and standardized experimental procedure in plant and water investigations, and contributed greatly to the application of research to commercial irrigation in California.

Water Requirements of Crops:

The amounts of water required to raise various crops to maturity received the attention of many workers during the early part of the century. Much of this research was conducted by growing isolated plants in small containers and determining the amount of water required to produce a given amount of grain or of dry matter. The results of such studies were local in application and were so greatly influenced by weather and general growing conditions from year to year as to be of limited value to agriculture. In addition, the effect of root-binding, water distribution, and excessive evaporation and transpiration in pot studies usually conducted in the greenhouse may have given results far from comparable to field crops grown under natural conditions.

Another type of study which flourished in early investigations and which is occasionally reported at the present time attempts to vary the soil moisture percentage in a series of pots holding the same type of soil. By adding successively larger amounts of water to each pot treatment, the investigator assumes that he has "maintained" each pot at a different soil moisture content, and that the resulting plant yield from each treatment indicates the soil moisture content best suited for the growth of the plant in that soil type. It will be demonstrated later in this report that each soil has a definite capacity for water and that it is a physical impossibility to irrigate a soil to a uniform soil moisture content other than its field capacity. Attempts to control the moisture content by adding different amounts of water to the surface result merely in completely wetting the soil to various depths.

Field studies on the water requirement of various crops have also been conducted. Usually the tests consist of careful measurement of water to small plots, and the determination of the ratio of irrigation water to the final weight of the crop. In general, such tests have shown that the better the conditions of soil moisture and fertility, the less the water requirement of the plant. No conclusive evidence has been presented to show that fertilization changes the moisture-holding properties of the soil, although many investigators have observed that the development of the root system, and consequently the extent of the soil moisture reservoir from which the plants feed, have been favorably affected by fertilization.

Single-Value Soil Constants:

The possibility of determining a single-value constant which would express the nature of a given soil as well as its properties in relation to agriculture has long been a fertile field of investigation.

The hygroscopic coefficient, defined as the percentage of water held in a soil initially dry which has been brought into a saturated atmosphere received the attention of early workers in Germany, Great Britain, and by Alway and his colleagues in Nebraska. The early investigators held that the hygroscopic power of the soil rendered water of the atmosphere available to plants, but subsequent research demonstrated that hygroscopic water was valueless in supplying moisture to growing plants. The difficulties of maintaining constant conditions of temperature and humidity, and the length of time required to make the determination have led to the general abandonment of the hygroscopic coefficient in agricultural investigations.

The use of the maximum water-holding capacity of soils was another attempt to obtain a single-value soil constant. This was a laboratory determination in which soil was placed in small brass tubes, saturated by standing in water, and allowed to drain for a definite length of time. The resulting soil moisture content was termed the "maximum water-holding capacity" and some proportion of it, usually 60 per cent, was considered the "optimum" moisture content of that soil. The analysis is affected by the way the soil is packed, the height of the soil column, and the temperature. This procedure is no longer in general use.

British workers, especially those in the Dominions, have a single-value soil constant called the "sticky point" and defined as the moisture content of heavy soils at the point of adherence without excess water. Hardy of Trinidad and Tempany of Mauritius also use the "shrinkage coefficient" as a measure of soil plasticity and colloidal content.

The volume weight or apparent density of soil is another single-value constant which, although presumably unaffected by soil moisture, is of importance in determining irrigation requisites of different soils. Various laboratory methods of analysis for this constant are objectionable due to the disturbance of the soil column when moved from the field to the laboratory. A number of methods have been developed for determining the volume weight in the field and expressing the result as the weight of soil per unit volume in terms of an equivalent weight of water.

The soil constant which has found greatest favor among American workers due to its rapidity and simplicity is the "moisture equivalent." This is also a laboratory procedure by which small samples of saturated soil are subjected for a definite length of time to a centrifugal force 1,000 times the force of gravity. The residual soil moisture content is termed the moisture equivalent.

The moisture equivalent and its procedure was first developed by Briggs and McLane, of the United States Department of Agriculture, in 1910 when the investigations on the soil moisture content when plants wilt, previously described, were being conducted. The Washington investigators found that a definite relationship existed between the moisture equivalent and the moisture percentage of that soil when plants wilted. This relationship was expressed by dividing the moisture equivalent by the wilting percentage. A ratio which averaged 1.84 was found for all soils used in the original investigations of Briggs and Shantz. Later research by

other workers, particularly by Veihmeyer and Hendrickson in California, indicates that in certain soils the ratio between these two factors may vary considerably. When applied to soils of the same geologic origin or geographic location, however, the moisture equivalent has proved to be the best available single-value constant for the relative classification of soils and for an indirect estimate of the soil's range of available moisture.

Movement of Soil Moisture:

In no phase of soil moisture investigations has there been more important progress than in studying the movement of water in the soil. As has been previously indicated, early workers in soil physics attached great importance to capillary action as a force in moving water from moist to dry soils. Such studies were conducted chiefly in the laboratory, using artificial substitutes to simulate the soil grains, and were concerned with mathematical analyses of the effect of viscosity, surface tension, and moisture-film curvature on the rate and extent of water movement.

Unfortunately the results of much of this research in artificial media was extrapolated to field soils, and a misconception of the relation of water and soil was created in the minds of scientists and farmers alike.

The value of capillarity in supplying plants with water from adjacent masses of moist soil frequently has been disproved. As early as 1889, King of Wisconsin noted the slow rate of capillary rise in a soil and doubted the ability of this force to supply plants with water unless the roots were in or close to the underground water table. He observed specific cases in which corn suffered from inadequate soil moisture although the roots were only 42 inches above the water table. Loughridge of California reported in 1894 that capillarity was extremely limited in extent and rate unless the soil surrounding the feeding roots was in immediate contact with a free-water table.

The advent of "dry farming" in the Great Plains again emphasized the ineffectiveness of capillarity in supplying water to plants. Burr in Nebraska found that "The movement of water thru the soil by capillarity is so slow that it is practically useless in bringing water from a lower soil area for the use of a growing crop"; while Thysell in North Dakota states, ". . . because of the absence of a free water table capillarity as a force for moving water upwards ceases and is of no practical importance."

The detrimental effect of surface evaporation in depleting soil moisture was also stressed by early agricultural workers who reasoned that as capillarity constantly moved water from the relatively moist subsoil to the surface, the greater part of the soil's water supply would be lost. The value of the soil mulch was therefore emphasized as an effort to prevent losses of moisture by evaporation. Repeated investigations by many workers, however, indicate strongly that surface evaporation in a normally compact soil without cracks is limited to the first few inches on the surface. Below this depth, water is removed from the soil in only one way—by the feeding of plant roots.

Alway, from studies in the Saskatchewan, concluded that roots go to the stored water in the subsoil instead of the latter being elevated by capillarity and that comparatively little water which has once passed below the plant is lost by evaporation.

Thysell came to the conclusion that the increased moisture content attributed to the soil mulch is due to the eradication of weeds. Otherwise the soil mulch can be disregarded. Veihmeyer of California, working with large tanks and with field plots, compared the moisture losses of cultivated areas with those of uncultivated areas in which weed growth was suppressed. He found that cultivation did not influence the losses of moisture by evaporation from the bare surfaces of soils nor did it materially influence the distribution of moisture in the soils.

A wealth of evidence by many other workers could be offered to support the belief that both capillarity and surface evaporation have little if any effect on the movement of moisture in normal well-drained soils, and that essentially the only means of soil moisture reduction in the soil is by root feeding and transpiration of cultivated plants and weeds.

The downward movement of water after irrigation or rainfall is of particular interest to the farmer. The accurate study of the factors involved can be made only in the field, as the laboratory investigations with artificial or disturbed soil often have led to erroneous results and impressions. The firmly established belief in the power of capillarity and surface evaporation, even in the face of evidence demonstrating its slight or non-existent effect, also tended toward a confused picture of soil water movement.

King, of Wisconsin, noted a very slow rate of penetration after a 1.4-inch rain, explaining the results on the basis that cultivation kept the soil cooler below the surface, strengthened capillarity, and tended to decrease the downward percolation of water. Loughridge, in 1908, found the downward movement of irrigation water to be very irregular in rate of movement as well as in the amount retained at various depths. He also observed in furrow irrigation that the water did not move laterally more than two feet. Many investigators now feel that the movement of soil water does not cease until equilibrium is established with the water table, although the time required for this adjustment to take place may be so great that it is of little benefit to growing crops.

A direct method of studying the movement of soil moisture after irrigation is that of cutting a trench across one or more irrigation furrows after water has been run for a definite length of time in the furrows. The extent of downward and lateral water movement can thus be observed and marked on the cross-section of the trench. Most workers who have used this method find that a rapid movement of moisture through the soil takes place for only a short time after water has disappeared from the surface, and soon reaches a state of equilibrium from which there is no significant movement of moisture. The vertical penetration of water is much greater in rate and extent than the lateral movement in uniform well-drained soils. The line between moist soil and dry soil is generally sharply defined. Veihmeyer has carried this method of study a step further by obtaining samples for total moisture and for moisture equivalent in the moist and dry areas of the furrow cross-section. He finds that *all* of the soil in the moist area holds the same proportion of water, which is essentially equal to the value of the moisture equivalent of that soil; while all of the soil in the dry area, even in that close to the dividing line, is relatively dry and shows no increase in moisture content which can be attributed to the current irrigation.

Surface Forces of Soils:

Still another phase of investigation which has received attention in Great Britain and the United States has been the study of the forces in the soil which influence its power to retain water. In general, the conclusions of many workers using various methods of analysis point to the fact that the water in a well-moistened soil is very loosely held by the surfaces of soil grains. As the soil dries out, the forces holding the water continue to be slight until a critical moisture content, dependent upon the nature of the soil, is reached. At this critical point, water is held by the soil with increasing tenacity and for each further increment of water loss the force tending to bind the water to and around the soil granules increases tremendously.

The significance of surface-force research to agriculture is that the soil moisture content at which the soil forces become increasingly effective is essentially the same as the permanent wilting percentage of that soil. Water is equally available to the plant from the time of irrigation to the time the wilting percentage is reached, after which soil water becomes increasingly difficult for the plant to obtain until it becomes entirely unavailable for growth.

Modern Conception of Plant and Soil Moisture Relations:

Thus, nearly a century of intensive investigation by many workers has led to a generally accepted conception of the relation of soil moisture to plant growth. Supported by many careful studies, these general statements may be summarized as follows:

1. *Each soil has a definite capacity for moisture which is inherent in the physical structure and chemical nature of that soil and does not change with season nor with the plant species grown therein.*

2. *After the soil surface is wetted by rainfall or irrigation, water moves downward by gravity and fills each increment of soil to capacity before lower increments receive any water. The depth to which rainfall or irrigation is effective is dependent entirely upon the physical capacity of the soil and the amount of water added to the surface.*

3. *In the absence of a free-water table a short distance below the surface, capillarity is not effective in moving water from a moist to a dry soil.*

4. *Surface evaporation reduces the moisture content of a normal compact soil to a depth of only a few inches. Cultivation and mulching as a means of conserving moisture below this surface layer are effective only in their ability to suppress weed growth.*

5. *Moisture can be drawn from the soil only by the feeding action of plant roots. Plant roots will not develop and extend in dry soil.*

6. *The rate at which moisture is drawn from the soil is dependent upon the nature of the plant, the leaf area exposed and the evaporating conditions of the atmosphere.*

7. *When the soil water has been reduced to a critical moisture content, commonly termed the permanent wilting percentage, plants obtain water with increasing difficulty, leaves wilt, and normal plant performance is severely handicapped or entirely stopped until the soil is again filled with water.*

8. The permanent wilting percentage is a function of the soil type and does not vary with season nor with the species and age of the plant.

9. In soils of similar geologic origin and geographical location, a laboratory analysis called the moisture equivalent provides an index of the physical nature and indicates indirectly the maximum and the minimum limits of readily available moisture in that soil.

Investigations in Hawaii

The lateritic nature of Hawaiian soils adds further complications to the study of soil and water relations. As early as 1894, Hilgard and Loughridge noted the unusual characteristics of soils from the "Sandwich Islands," and added "The moisture coefficient is extremely high in all soils examined."

Early Research of Maxwell and Eckart:

One of the first soil properties studied by Dr. Walter Maxwell, first Director of the Experiment Station, H.S.P.A., was the power of Hawaiian soils to absorb and retain moisture. In 1896 he reported the results of a study on 20 samples of Hawaiian cane soils from the islands of Oahu, Maui, and Kauai which he packed in metal cylinders, immersed in water, and determined the amount of water absorbed and retained. While Maxwell recognized that the tests ". . . do not state the behavior of the soils in their places in the fields . . . ," the fact that the absorptive power of the soils varied from 31.8 to 86.9 per cent led him to emphasize that ". . . organic matter is a predominating factor in the relation of soils to water" and that there is ". . . an absolute need of first determining the absorptive power of each soil before the application of water."

Maxwell also conducted studies on the transpiration of cane plants grown in tubs over a free-water table. His results led him to the conclusion that cane grown under the conditions of the experiment transpired nearly 2½ times as much water at the age of six months as it did during the first month of growth. Transpiration of the cane plant was nearly twice as great during hot sultry weather as it was under normal trade-wind conditions although evaporation from a bare soil surface was greater under the latter conditions.

Schuyler and Allardt, civil engineers investigating water supply and requirements for new plantations in Hawaii, made the following interesting comments on irrigation practice on leeward Oahu in 1889: "Three waterings a month is the least that is considered safe to apply to keep the cane growing without check. In localities corresponding in position and climate with Honouliuli it is customary to maintain this periodical irrigation regardless of the rainfall. The rain may at times exceed the quantity applied artificially, but irrigation is performed as usual notwithstanding, in order that there shall be no break in the continuity of the waterings. It seems to be generally understood by all planters that the depth of each watering shall be at least an average of 3 to 4 inches over the whole surface." These writers also stated that the general manager of the plantation at Spreckelsville added that within reasonable limits it was almost impossible to put on too much water and that the more water applied the greater the yield.

Maxwell took exception to the low duty of water reported by the early plantations and conducted small plot experiments over a period of three crops from 1897 to 1900 in which he produced better than 12 tons of sugar with 2.5 million gallons of water as compared to plantation reports of less than 6 tons of sugar for 5 million gallons of water. Maxwell adds, "The . . . data show what has been done and what it is possible to do, where the irrigation is carried out according to scientific principles and where the conditions are under control. Upon a large plantation the conditions cannot be controlled to the same extent as is possible with experiments on limited areas. This in no wise lessens the force of the fact that plantations are wasting huge volumes of water in their practice of irrigation or removes the necessity of . . . determining the location and causes of the waste."

Lysimeter tests conducted at the same time led Maxwell to state, ". . . only so much water can be put on [the soil] without its being wasted. . . . These facts tell us that if we put on more than a given quantity of water the soil cannot hold it." Eckart continued the field plot experiments from 1903 to 1905, varying the amounts of water to five plots planted to Lahaina and Rose Bamboo varieties of cane. Apparently the treatments were continued regardless of the season or weather conditions.

Attention to irrigation requirements and the effect of water on sugar cane lapsed after 1905, although H. B. Penhallow suggested in 1913, "A scientific study of our soils with a view to determine how much irrigation they will stand and how much water is necessary to produce a given quantity of sugar will give as sure a return as any improvements which have been made in the process of manufacture."

Work of Allen at Waipio Substation:

The first program of intensive study on the relation of soil moisture to crop production was conducted by R. M. Allen at the Waipio substation from 1916 to 1920. He traced the extent of soil moisture movement in Waipio soils by auger sampling, and concluded that it was impossible to store, in the upper six feet of a Waipio soil, more than 4½ inches of water, of which about 2½ inches was retained by the surface two feet of soil. Practically the same amount of water was retained in the soil regardless of the amount of irrigation water applied.

After completing an irrigation experiment in which the amounts of water per acre per crop varied from 2.45 to 8.79 acre-feet without obtaining any significant difference in cane yield, Allen observed, "The true value of an irrigation is measured not by the amount of water that is applied to the soil, but by the amount of moisture that is retained by the soil and the manner in which this is distributed throughout the soil area both laterally and perpendicularly."

The first approach locally to the present conception of the wilting percentage was reported by Allen when he stated in 1919, "We have found that on our medium soil at Waipio whenever cane looks as if it needed water, the moisture percentage is below 23%. This means that when our moisture percentage gets as low as 25% it is time to irrigate, for we should not wait until the cane is suffering before we apply water, for at such time its growth is checked." He noted further that the appearance of the soil or of the plant is not a proper criterion of the time to irrigate.

Allen's work on soil moisture at Waipio apparently stimulated interest in irrigation investigations throughout the Islands, and a number of plantations conducted experiments based on soil moisture observations.

H. W. Baldwin of Maui Agricultural Company observed in 1920: "It has frequently been said that seepage water is not lost to the cane, but eventually finds its way to the roots. . . . In order to test out this point, soil moisture tests to a depth of 6 feet were made at one-foot intervals distant from a dry watercourse. . . . and water allowed to run in the watercourse for an hour and fifteen minutes. Two days later soil samples were again taken and it was found that the soil moisture at a distance of one foot from the watercourse had increased 3.85%; two feet away, 3.12%, and three feet away, only 1.04%, thus showing that the lateral penetration was very slight. . . ."

Work of Alexander at Ewa:

W. P. Alexander at the Ewa Plantation conducted soil moisture observations on three different soil types from August 1921 to April 1922. He concluded that the maximum which could be retained by these soils was about 30 per cent and that ". . . irrigation water applied after this point is reached is wasted." His data showed, ". . . practically no capillary movement of the water from the lower feet to upper strata of soil. The drying out process proceeded downward, being rapid in the first two feet." By observation he set the wilting point of cane as below 21 per cent, and added, "This might be called the danger point, above which soil moisture must be kept to maintain normal growth. To allow the soil moisture to reach this point before applying irrigation water would be retarding the growth of the cane plant."

Interval Tests:

Alexander pointed out some of the difficulties of obtaining representative soil moisture samples in the field, and turned in 1923 to the development of the "interval test" as a means of gaining information on the irrigation requirements of their plantation soils. These experiments compared the growth, water consumption, and yields under three irrigation treatments in which the variable was the length of time between irrigations. By a maximum treatment, the cane received frequent irrigations at a rate more rapid than was popularly considered practicable with the irrigation methods and available water supply in use; a normal treatment supplied the cane with adequate irrigations as based on the best conditions the plantation could offer; and by a minimum treatment, irrigations were made as seldom as possible without allowing the cane to die. A fourth treatment—plantation practice—by which irrigation water was applied at the same time as that to the surrounding field, was occasionally added. The interval between irrigations to each plot series was determined somewhat arbitrarily by past experience and collateral investigation.

The success of the interval tests at Ewa led to their adoption on other plantations, particularly those of the Pioneer Mill Company, Koloa Sugar Company, and Lihue Plantation Company. The relative merits of the interval test as a means of irrigation investigation do not need analysis here. The experiments were of direct value to many of the plantations, provided a rapid and relatively accurate method of estimating the water requirements and rate of irrigation in various areas, and stimulated a renewed interest in irrigation studies and the evaluation of water.

Irrigation Investigations at Waimanalo:

A collaborative irrigation experiment between the Experiment Station and the Waimanalo Sugar Company was started in June 1923 and compared plantation practice with "complete irrigation" on large plots in two typical fields of the plantation. Soil moisture sampling and cane growth measurements were used as criteria of irrigation. The reports on the project emphasize the different moisture requirements of various soils of the plantation. The Waimanalo tests emphasized again the results obtained by Allen at Waipio: "The true value of an irrigation is measured not by the amount of water that is applied to the soil, but by the amount of moisture that is retained by the soil and the manner in which this is distributed. . . ."

The Waimanalo investigations turned from soil moisture and cane growth determinations toward the measurement of field consumption and seepage losses over the plantation although Beveridge noted in 1927 that soil moisture sampling was still used as a field guide, ". . . the beginning and end of the irrigation season is largely decided by means of soil moisture determinations. Irrigation commences in the spring as soon as the soil moisture has dropped appreciably below the optimum point in many of the fields. In the same way the season is closed in the fall, when the soil moisture has increased and the appearance of the cane indicates an adequate supply of water in the soil."

Irrigation Studies by Oahu Sugar Company:

The Oahu Sugar Company in 1924 inaugurated a program of irrigation investigations which included studies of soil moisture and cane growth relationships in four fields of widely varying soil types. The studies were especially concerned with the soil moisture content required for maximum growth. The approach to the present conception of the wilting percentage as a function of the soil type is shown by the following extract from a report in 1928 by the plantation agriculturist, William Wolters, who stated that in each of four typical fields, ". . . check plots (plantation practice) are compared with control plots. The check plots are irrigated at the same time as the surrounding crop cane. The control plots are irrigated . . . whenever . . . the soil moisture content reaches a 'zero point' which, by experimentation, calls for an application of water. The 'zero point' is not a fixed figure, since it is governed by seasonal variations. This point is established as a result of past experience, based on soil type, irrigations and rate of growth. Each soil type has its own 'zero point.' "

The arrival in 1928 of Prof. Wadsworth of the University of Hawaii and his affiliation with the Experiment Station in an advisory capacity, stimulated renewed research on plant growth and soil moisture. Prof. Wadsworth, from his familiarity and association with the work of Veihmeyer and others in California, aroused general interest in the modern conception of plant and water relations which the independent plantation studies previously described had approached. In 1929, Wadsworth and Das repeated the procedure of Briggs and Shantz in determining the permanent wilting percentage of a Waipio soil and discovered that the wilting percentage for beans, sunflower, and sugar cane in the soil used was essentially equal. They noted, however, that cane leaves do not exhibit the obvious symptoms of wilt shown by other plants, and judged the wilting percentage when cane was used as the indicator plant by the soil moisture content at which a change in the transpiration rate occurred.

The Waipio investigations, described separately in this report, were conducted from 1928 to 1932, and attempted to determine the important soil moisture constants of Hawaiian plantation soils as well as to establish the basic principles on which Hawaiian soils compare with those of other parts of the world. In general, the investigations demonstrated the fact that the modern conception of plant and water relations is applicable to the soils of Hawaii and that the general laws governing the movement and availability of soil moisture are universal in their application.

Studies by the Association of Hawaiian Pineapple Canners:

The Experiment Station of the Association of Hawaiian Pineapple Canners also became interested in the application of soil moisture relationships to their plantation soils. Farden analyzed the soil moisture constants of three pineapple soils from the island of Oahu. He found a ratio between moisture-holding capacity and moisture equivalent of 1.11, and between the wilting percentage, using sunflower and peas as indicator plants, and the moisture equivalent of about 1.45. Dean and Abel determined the volume weight of the topsoil and subsoil of a number of pineapple soils. Wadsworth attempted to determine the wilting point of pineapple plants but found that the physiological structure of the plant did not permit obvious symptoms of wilt.

Work of Penhallow at Honolulu Plantation Company:

The first application of the modern conception of soil moisture relationships to plantation field experimentation was made by Penhallow at Honolulu Plantation. He grouped the soils of the plantation into three general classes, based on the moisture equivalent. Periodic soil moisture determinations and growth measurements were taken in representative areas of each soil group, and the rate of soil moisture depletion and the growth rate of the cane determined throughout the progress of the crop. He also conducted an experiment in which the value of various depths of irrigation penetrations were compared. Water was applied when the soil moisture reached an arbitrary minimum of 25 and 30 per cent for red residual soils and of 35 and 40 per cent for adobe soils.

From his data, Penhallow concluded that for residual red soils, "Penetration of irrigation water to a depth of two feet below the surface of the soil is sufficient for the plant's needs and results in water economy. . . . It seems better for the crop in both yield of cane and water economy to allow the soil to dry out to a minimum average moisture content of 25% before re-irrigating. A minimum moisture content between 25% and 30% may be better than either." It should be observed that from the Waipio investigations, which found an average ratio of 1.25 between moisture equivalent and permanent wilting percentage for all soils examined, the predicted wilting percentage from the moisture equivalent values reported by Penhallow should be about 28.0 per cent.

The results of the Honolulu Plantation investigation led to the establishment of a schedule of irrigation intervals for the plantation fields based on the soil type, season, and time the crop started.

An irrigation experiment based on a recent suggestion by Das was installed at the Waipio Substation in 1936. Das suggests that the interval between irrigations may be indicated by the maximum temperature, with an application of water being made when the accumulated day-degrees (daily maximum temperature less 70° F.) from

the last irrigation reaches 200. The experiment is designed to study the effect on cane growth and yield of cane and sugar from irrigations spaced on the basis of 150, 200, and 250 elapsed day-degrees, as well as a comparison with plots irrigated whenever the soil moisture is reduced to the wilting percentage. The success of the experiment is dependent upon a high correlation between maximum daily temperature and the rate of plant transpiration or soil moisture depletion. The results will be watched with interest.

Waipio Investigations on Plantation Soils:

A series of correlated experiments on the basic relationships existing between soil moisture and cane growth on typical Hawaiian cane land soils was conducted at the Waipio substation from 1928 to 1932. The investigations were designed to study whether or not, and to what degree, the conception of plant and water relationships evolved in fifteen years of investigation on Mainland soils applied to the lateritic soils of Hawaii.

Soil Moisture Constants: The first phase of the investigation was to determine some of the fundamental soil moisture constants of widely varying soil types from the islands of Oahu, Maui, and Kauai. Determinations of the maximum field capacity were made by auger samples at interval depths of one foot to a total depth of six feet. The sample area was flooded, 12 samples per foot of depth taken 48 hours after flooding, and the moisture content determined in the Waipio substation laboratory. Volume weight analyses were made at the same time by determining the oven-dry weight of all the soil removed from a one-foot boring and the weight of oil of known specific gravity required to fill the hole. The volume weight was expressed as the ratio of oven-dry soil weight to the weight of an equal volume of water. Samples for moisture equivalent and wilting percentage determinations were taken from the field at the same time, the analyses being made at the Waipio substation.

The volume weight of 105 determinations at various soil depths in 25 plantation fields were comparable to each other in their trend. With normal loam soils of fairly even texture, a low volume weight of 1.0 or less exists in the topsoil within the limits of plowing. The volume weight below this point increases rapidly to a value ranging from 1.1 to 1.5 in the third to six foot of depth. Below the second foot, the volume weight of each depth increment is rather constant in most soils. Kauai soils, in particular, show a marked difference in volume weights between topsoil and subsoil. The volume weights of Hawaiian soils studied are not widely different from those reported in the literature on soils of other geologic origin in Europe and Mainland United States.

The moisture equivalent, on the basis of 133 comparisons in the 25 soil types studied, appeared to hold considerable promise as an index of the physical structure of the soil and particularly as a consistent measure of the soil's capacity for holding water. The relationship between the moisture equivalent and the maximum field capacity was surprisingly consistent over a wide range of soil types, the best value being moisture equivalent x 1.1 = maximum field capacity. Subsequent studies on well-weathered soils of the unirrigated Hilo and Hamakua districts of Hawaii, however, do not show a consistent relationship between the moisture equivalent and other soil moisture constants. The relationship between moisture equivalent and maximum field capacity is shown graphically in Fig. 1.

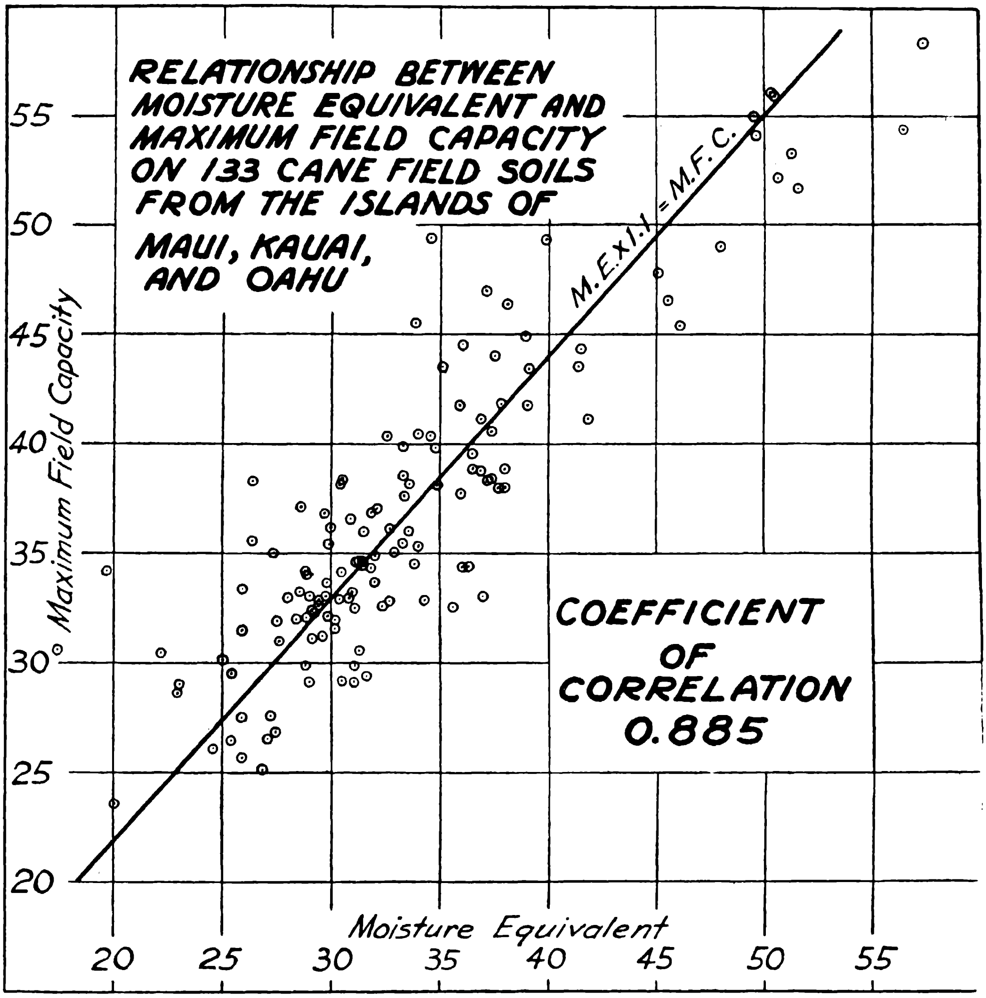


Fig. 1. Relationship between moisture equivalent and maximum field capacity on 133 cane field soils from the islands of Maui, Kauai, and Oahu.

A summary of the soil moisture properties analyzed for 25 plantation soils is given in Table I.

TABLE I

SOIL MOISTURE CONSTANTS OF TYPICAL HAWAIIAN CANE LAND SOILS

Plantation	Field	Elevation	Color	Character	Depth Sampled	No. of Samples	Volume Weight	Max. Field Capacity	M. E.	RATIO Max. Field Capacity ÷ M. E.
Oahu Sugar Co.	38	300′	Red-Brown	Light, Pervious	6′	72	1.13	34.5	30.8	1.10
Oahu Sugar Co.	53	600′	Dark Red	Medium heavy	6′	72	1.19	34.5	31.2	1.11
Oahu Sugar Co.	3A	315′	Dark Red	Fine	6′	70	1.24	33.7	30.6	1.10
Ewa Plantation Co.	"A"	59′	Brown-Black	Heavy	5′	60	1.34	26.1	25.7	1.02
Ewa Plantation Co.	22C	24′	Red over Coral	Light	1′	24	0.43	43.6	35.1	1.24
Ewa Plantation Co.	20A	45′	Black	Heavy	2′	13	0.71	34.1	30.5	1.12
Waimanalo Sugar Co.	26	5′	Black	Heavy	3′	66	0.58	57.2	56.7	1.01
Waimanalo Sugar Co.	18	150′	Dark Brown	Medium	6′	71	1.09	52.9	49.8	1.06
Waimanalo Sugar Co.	13	50′	Black	Heavy	4′	48	1.02	49.3	48.0	1.03
Pioneer Mill Co.	32D	150′	Red	Coarse	6′	72	1.16	34.5	29.8	1.16
Pioneer Mill Co.	LA6	900′	Light Red	Fine	4′	42	1.02	36.0	32.1	1.12
Pioneer Mill Co.	B2	1200′	Dark Red	Medium heavy	6′	71	1.11	36.8	32.6	1.13
Pioneer Mill Co.	B8	650′	Red	Medium	6′	72	1.20	31.6	28.8	1.10
Haw'n Com'l & Sugar Co.	"P"	....	Red	Medium	6′	72	1.11	37.6	32.4	1.16
Haw'n Com'l & Sugar Co.	2	250′	Brown-Black	Coarse	6′	72	1.18	29.5	25.2	1.17
Haw'n Com'l & Sugar Co.	"A"	40′	Red	Medium	6′	71	1.19	37.3	31.1	1.20
Haw'n Com'l & Sugar Co.	"L"	140′	Brown	Medium	2′	24	0.90	28.4	25.2	1.13
McBryde Sugar Co.	20B	550′	Dark Brown	Fine	6′	72	1.17	44.0	40.2	1.10
McBryde Sugar Co.	13D	400′	Dark Brown	Fine	6′	72	1.23	37.9	36.9	1.03
McBryde Sugar Co.	3A	160′	Red	Fine	6′	72	1.25	37.0	31.5	1.17
Lihue Plant. Co.	20H	350′	Dark Brown	Medium	6′	72	1.12	46.5	37.8	1.23
Lihue Plant. Co.	20L	207′	Red-Brown	Granular	6′	72	1.20	39.4	37.4	1.05
Lihue Plant. Co.	30	95′	Dark Red	Medium	6′	71	1.43	31.4	30.8	1.03
Kekaha Sugar Co.	421	750′	Red	Medium	6′	72	1.15	32.2	32.8	0.98
Kekaha Sugar Co.	20	5′	Brown-Black	Heavy	4′	63	0.83	47.7	45.0	1.05

Movement of Soil Water: Laboratory and field tests were conducted on the vertical and lateral movement of water in the soil after an irrigation. Detailed results of the experiments were reported in *The Hawaiian Planters' Record* for January and April, 1932.

To determine the extent of vertical water movement in a soil, a Waipio soil of 35 per cent field capacity was oven-dried, and packed in five waterproofed cardboard cartons. Various amounts of water, sufficient to bring the average moisture content of the soil to 10, 20, 25, 30 and 40 per cent respectively, were added to the soil surface. After 48 hours the cartons were cut open at one-inch increments, and the distribution of the water studied by observation and by obtaining the moisture content of each soil increment. The results were as shown in Fig. 2.

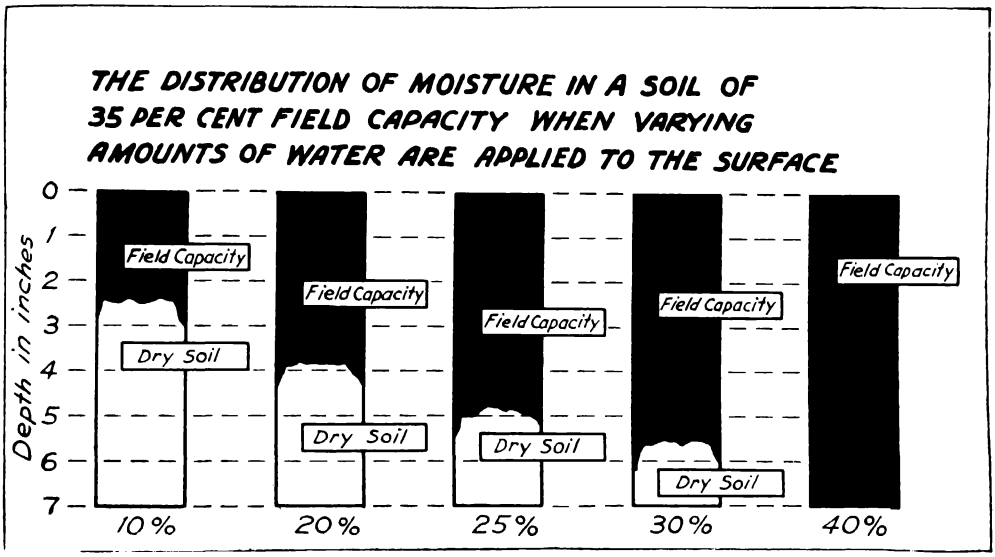


Fig. 2. The distribution of moisture in a soil of 35 per cent field capacity when varying amounts of water are applied to the surface.

Obviously the distribution of moisture throughout the soil mass when a predetermined weight of water is added to the surface is far from uniform. Apparently a given soil has the capacity of holding around its granular structure a certain quantity of water. When the surface increment of dry soil has satisfied its capacity for moisture, water descends to the next lower soil increment, where sufficient moisture is absorbed to satisfy the capacity of the second increment. This sequence is continued until all of the water is held by the soil. The soil at the lower depths receives little if any water until the absorbing power of the upper increments has been satisfied.

Field studies on the distribution of soil moisture under different methods of irrigation were made at the Waipio substation on contour irrigation, at Waimanalo on long-line irrigation, and at Ewa Plantation on the border method of irrigation. Forty-eight hours after irrigation, a trench was cut athwart the furrow or border at various distances from the headgate. The dividing line between moist soil and relatively dry soil was usually clearly defined on the cross-section of the furrow. The outline of the wetted soil zone was marked by nails thrust in the soil, and plotted on cross-section paper. Soil samples for total moisture content and for the moisture equivalent were taken inside and outside the moist area, and the results expressed as

"Relative Wetness" or ratio between the moisture content of the soil after irrigation and its capacity for water as measured by the moisture equivalent. Soil samples were taken repeatedly from the area just below the dividing line for several days after the irrigation to learn if any further movement of water by capillarity had occurred. This method of study, frequently used in Mainland investigations, was first employed locally by T. K. Beveridge of the Waimanalo Sugar Company.

Typical examples of such field studies on soil water movement and distribution are shown in Figs. 3, 4 and 5 for each of the irrigation methods studied. The more important results of these studies may be summarized as follows:

1. *Factors which appear to have direct bearing on the distribution of soil moisture after irrigation are: the nature, depth, and texture of surface soil and subsoil; the slope and gradient of the land; and the depth of the free-water table below the ground surface. The nature and depth of the subsoil below the surface appear to have a decided effect on the shape of the wetted zone.*

2. *After a light irrigation to a normal loam soil by the contour or long-line methods of irrigation, the wetted area is elliptical in shape with its major axis in a horizontal direction. With heavier applications of water, the lateral spread of water does not increase materially but the vertical penetration increases proportionately to the intensity of the surface application.*

3. *The soil at all points within the wetted area caused by the irrigation is at its maximum field capacity. The soil immediately outside the perimeter of the wetted zone is considerably below its field capacity, and in all probability receives no water from the current irrigation.*

4. *In a well-drained loam soil, there is no appreciable movement of water from moist to dry soil by capillary attraction, within the short-time intervals involved.*

5. *Under the contour and long-line methods of irrigation, the lateral penetration of water in the soil does not exceed 30 inches and is seldom more than 20 inches on either side of the center of the furrow.*

6. *Under border irrigation, the size and shape of the wetted soil zone after the irrigation is dominated chiefly by the permeability of the soil to water, by the slope, and by the side-to-side gradient of the border.*

Studies on the Wilting Percentage: The determination of the permanent wilting percentage of a number of plantation soils was made in 1929 and 1930. In brief, the method of determination consisted of growing sunflower plants and small cane plants in pots containing a known weight of dry soil. The pots were sealed so that moisture losses could be attributed only to transpiration through the plant. The soil moisture content at the time the plants appeared to suffer from inadequate soil moisture was determined from the weight of the system. The point of suffering was determined from the appearance of the leaves in the case of sunflower, and by actual measurement of the cessation of growth in the cane plants. A detailed discussion of the methods, which follow essentially those of Briggs and Shantz, Veihmeyer and others in similar studies elsewhere, is contained in a mimeographed report issued in May 1931, to plantation members of the H.S.P.A.

Repeated determinations of the wilting percentage on three Oahu soils indicate that plants as diverse botanically as sunflower and sugar cane deplete the soil moisture to essentially the same degree of dryness before the plants exhibit signs of distress because of inadequate moisture. (Table II.)

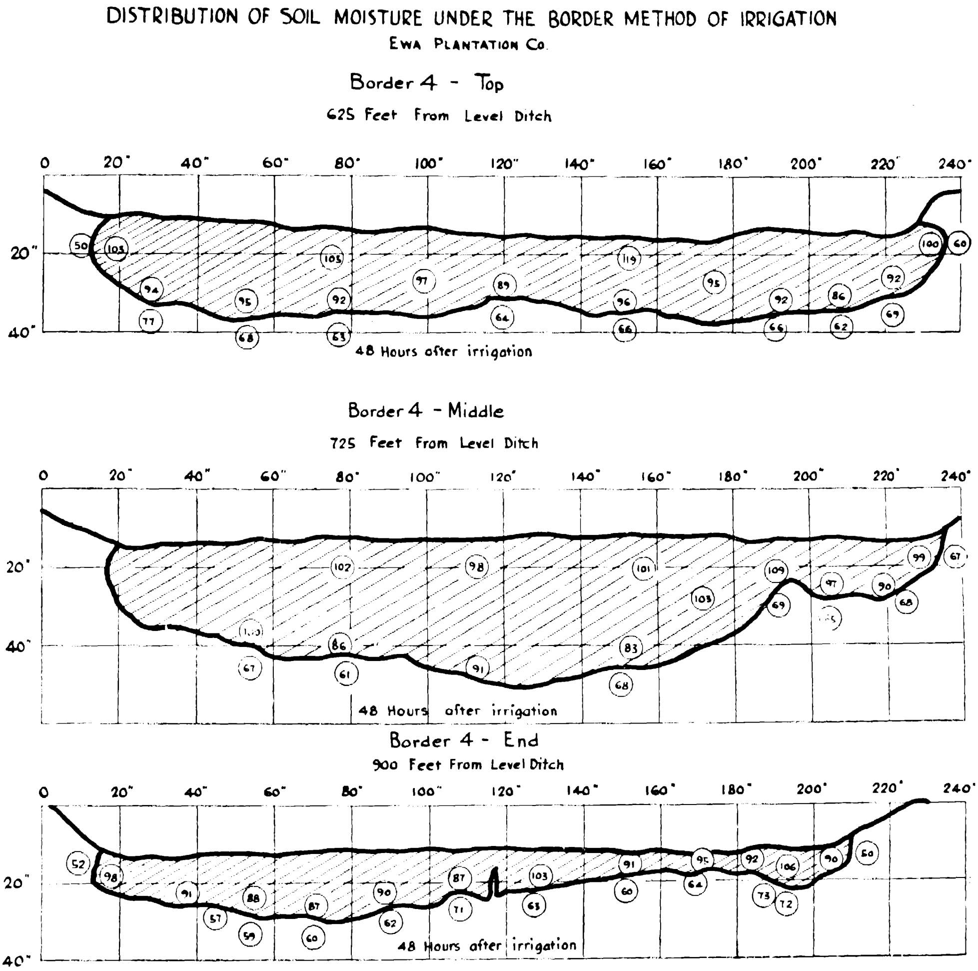


Fig. 5. Distribution of soil moisture under the border method of irrigation. Figures in circles refer to the "relative wetness" of the soil, or total per cent moisture × 100 divided by the moisture equivalent.

TABLE II

RELATION OF SOIL MOISTURE CONTENT AT PERMANENT WILTING OF SUNFLOWER PLANTS AND OF COMPLETE GROWTH CESSATION OF SUGAR CANE

Soil Series	Soil Depth	Soil Moisture Content at Permanent Wilting: Sunflower	No. of Determinations	Sugar Cane	No. of Determinations
Oahu 3-A	1	27.1±0.10	25	26.4±0.12	20
	2	25.5±0.15	17	25.3±0.07	20
	3	24.4±0.07	19	24.3±0.17	15
	4	24.6±0.08	20	25.4±0.18	16
	5	24.6±0.05	18	24.7±0.11	13
	6	24.6±0.08	21	24.6±0.08	21
	Average	25.2±0.07	120	25.2±0.07	120
Oahu 53	1	25.7±0.15	24	27.0±0.08	19
	2	26.1±0.06	19	25.9±0.10	22
	3	24.0±0.06	17	25.5±0.11	24
	4	24.3±0.05	18	25.8±0.09	15
	5	26.6±0.05	18	26.9±0.06	26
	6	26.5±0.09	17	27.0±0.05	18
	Average	25.6±0.07	113	26.4±0.05	124
Oahu 38	1	21.9±0.07	35	23.9±0.08	43
	2	21.3±0.07	34	22.9±0.08	32
	3	21.1±0.06	38	23.4±0.09	43
	4	25.0±0.07	36	25.7±0.07	36
	5	24.9±0.05	36	25.7±0.06	38
	6	25.1±0.06	37	25.9±0.11	27
	Average	23.3±0.08	213	24.5±0.06	219

The wilting percentages of other Hawaiian soils were determined with sugar cane as the indicator plant and with complete cessation of measured growth as the criterion of the critical lower limit of available soil moisture. The results of 952 observations on 45 soil series, showing consistent trends with acceptable probable errors in each trial, are given in Table III.

TABLE III

SOIL MOISTURE CONTENT AT PERMANENT GROWTH CESSATION OF SUGAR CANE IN VARIOUS HAWAIIAN PLANTATION SOILS

Soil Series	Depth	No. of Determinations	Permanent Wilting Percentage: Per Cent Soil Moisture	Probable Error: Single Observation	Probable Error: Mean	Moisture Equivalent	RATIO M.E./W.P.
Oahu 3A	1	20	26.4	±0.54	±0.12	34.9	1.32
	2	20	25.3	±0.31	±0.07	32.1	1.26
	3	15	24.3	±0.66	±0.17	28.4	1.17
	4	16	25.4	±0.72	±0.18	29.8	1.17
	5	13	24.7	±0.40	±0.11	30.3	1.23
	6	21	24.6	±0.37	±0.08	28.0	1.14
	Average	120	25.2	...	...	30.6	1.21
Oahu 53	1	19	27.0	±0.35	±0.08	34.6	1.28
	2	22	25.9	±0.47	±0.10	31.5	1.22
	3	24	25.5	±0.54	±0.11	29.4	1.15
	4	15	25.8	±0.35	±0.09	30.2	1.17
	5	26	26.9	±0.30	±0.06	28.7	1.10
	6	18	27.0	±0.21	±0.05	31.8	1.18
	Average	124	26.4	...	...	31.2	1.18
Oahu 38	1	43	23.9	±0.52	±0.08	31.5	1.32
	2	32	22.9	±0.45	±0.08	29.6	1.29
	3	43	23.4	±0.59	±0.09	29.0	1.24
	4	36	25.7	±0.36	±0.06	31.1	1.21
	5	38	25.7	±0.37	±0.06	31.4	1.22
	6	27	25.9	±0.67	±0.11	30.8	1.19
	Average	219	24.5	...	...	30.8	1.26
Ewa "A"	1	18	22.4	±0.60	±0.14	25.8	1.15
	2	9	22.6	±0.34	±0.11	25.3	1.12
	3	43	21.5	±0.78	±0.12	24.6	1.14
	4	32	21.3	±0.40	±0.07	25.8	1.21
	5	30	17.3	±0.37	±0.06	26.8	1.55
	Average	132	20.7	...	...	25.7	1.24
Ewa 20A	1	44	24.3	±0.77	±0.11	32.1	1.32
	2	33	23.3	±0.58	±0.10	29.0	1.24
	Average	77	23.9	...	...	30.5	1.28
Ewa 26B	1	23	26.9	±0.81	±0.17	36.1	1.34
	2	28	27.6	±0.93	±0.18	36.3	1.31
	3 (Coral)	16	26.7	±0.59	±0.15	27.1	1.01
Ewa 22C	1	29	26.3	±0.90	±0.17	35.1	1.33
Waimanalo 18	1	16	32.9	±0.40	±0.10	46.1	1.40
	2	11	37.9	±0.45	±0.14	51.5	1.36
	3	8	38.7	±0.33	±0.11	51.2	1.32
	4	7	38.5	±0.98	±0.37	50.4	1.31
	5	4	37.4	±0.47	±0.23	50.3	1.34
	6	3	37.1	±0.94	±0.54	49.6	1.34
	Average	49	36.4	...	...	49.8	1.37
Waimanalo 13	1	17	32.1	±0.59	±0.14	45.5	1.42
	2	5	41.8	±0.99	±0.44	47.9	1.14
	3	2	36.6	±0.24	±0.17	50.7	1.38
Pioneer E2	1	33	24.6	±0.52	±0.09	30.8	1.25
	2	16	24.7	±0.58	±0.14	30.0	1.21
	3	11	23.5	±0.77	±0.23	31.0	1.32
	4	3	26.0	±0.27	±0.15	32.7	1.26
	5	8	27.9	±0.21	±0.07	36.5	1.31
	6	18	28.2	±0.88	±0.21	34.8	1.23
	Average	89	25.6	...	...	32.6	1.27
Pioneer O2	1	22	18.5	±0.67	±0.14	22.9	1.24

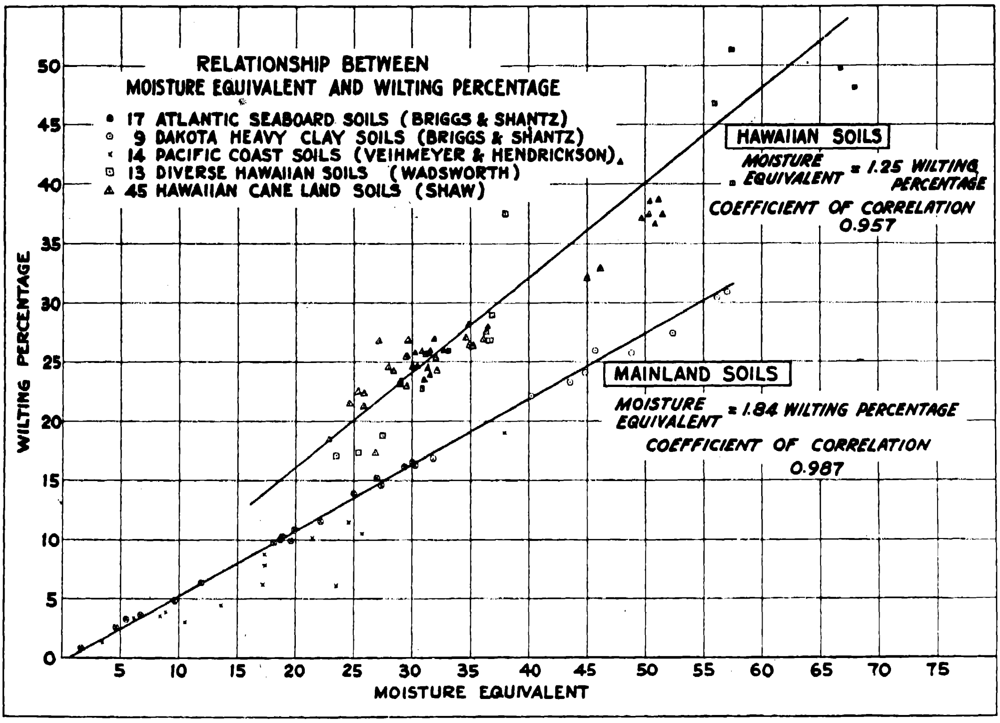


Fig. 6. Relationship between moisture equivalent and wilting percentage.

The relationship between the wilting percentage and the moisture equivalent is illustrated in Fig. 6. Here are shown the results of the original work by Briggs & Shantz as reported to the American Society of Agronomy in 1911, and the exceptions noted by Veihmeyer and Hendrickson, in *Plant Physiology* for 1928, to the constant ratio of 1.84 between the two soil moisture constants. On the same scale are shown the results of the 45 series of determinations on Hawaiian soils reported in this paper, and those reported by Wadsworth in 1933 on diverse Hawaiian soils from the islands of Maui and Hawaii.

Although there can be no doubt of the general relationship and trend between the moisture equivalent and the wilting percentage of any soil, the ratio between these two factors on Hawaiian soils is far different than that of most Mainland soils. The difference may be due to the character and quantity of the colloidal material of local soils, or to the difficulties in preparing field samples for the determination of both moisture equivalent and wilting percentage.

A ratio of 1.25 between moisture equivalent and wilting percentage appears to give a reasonable approximation of the lower limit of available soil moisture for most Hawaiian soils studied, particularly for the red residual soil which forms a major portion of the irrigated sugar lands of Hawaii. However, there are enough exceptions and departures from the general ratio to make the use of the moisture equivalent for this purpose advisable only in first approximations of the wilting percentage value. For precise estimates of this critical soil moisture constant, actual determinations should be made by measurement in the field, as described in a subsequent chapter.

"Tank" Studies: The next phase in the Waipio investigations of 1928-1932 was a study by Prof. Wadsworth and the writer on the growth and water relations of sugar cane grown to maturity in large tanks having a capacity of over one ton of soil. The specifications of the tanks and the general procedure were copied directly from the original work of Veihmeyer on orchard trees in California, with such modifications as were necessary in view of the different nature of the crop grown.

Two crops of eighteen months each were grown in the tanks under carefully controlled moisture conditions. In general, the results substantiated the major premises of the modern conception of plant and water relations. The cane grew at a constant rate, affected only by seasonal changes, after irrigation water was applied. When the soil moisture percentage reached a critical value, 23.3 per cent in this particular soil, the growth rate was greatly affected and elongation soon ceased entirely. The same disturbance of growth occurred at precisely the same soil moisture content throughout the life of the cane during both crops, being unaffected by season of year or age of cane. Considerable quantities of water were transpired by the cane even when the soil moisture was too low to permit active plant growth. Soon after irrigation water was applied to the soil, the cane resumed essentially the same rate of growth which it had enjoyed prior to the period of water privation. In a few extreme cases, however, when water was withheld for long periods of time the rapidity of recovery and the resulting growth rate were detrimentally affected for the remainder of the crop.

Field Studies and Observations: Observation and experimentation in the field under normal growing conditions demonstrated that a reliable index of the rate of crop growth could be obtained by the measurement of 20 stalks of cane in close proximity. The typical straight-line curve of cane growth for some time after irrigation, and the obvious break in the curve when the soil moisture was at the wilting percentage indicated that soil moisture and cane growth observations might be used as a guide in predicting the irrigation requirements of commercial fields of sugar cane.

Modern Conception of Plant and Water Relations in Hawaiian Soils:

The substantiation and modification of the modern conception of plant and water relations as they apply to most Hawaiian soils may be summarized as follows:

1. *Studies in Hawaii as early as 1896 recognized the variation in the power of Hawaiian soils to hold moisture. Many local investigators have noted that soils can hold only a definite amount of water and that additional water was wasted by deep penetration.*

2. *The limited movement of water from moist to dry soil by capillarity and the limited extent of lateral moisture movement in the soil was early recognized by investigators in Hawaii.*

3. *Experiments conducted from 1916 to 1926 on plantations of the Territory approached the conception of a wilting percentage or lower limit of available soil moisture. In general, however, the wilting percentage was apparently considered as a function of the cane plant rather than of the soil, subject to seasonal variation and to the age and variety of the cane.*

4. Studies by the Experiment Station, H.S.P.A., since 1928 have attempted to determine basic relationships between the cane plant, plantation cane land soils, and irrigation water with the view of obtaining methods by which commercial irrigation could be guided more economically and skillfully.

5. Investigations conducted in the laboratory, in pot tests, in large tanks, and in the field have established certain fundamental relationships which may well be considered and used in commercial irrigation:

a. Cane growth is independent of the soil moisture content for some time after irrigation, the growth rate being influenced only by season, age of cane, and by cultural operations other than irrigation.

b. Cane growth is severely affected, and may cease entirely, when the soil moisture content reaches a critical value which is dependent upon the physical nature of the soil rather than upon the type of plant or the season.

c. The cane plant does not exhibit external symptoms of wilt for several days after the critical limit of available soil moisture for growth has been reached. The appearance of the plant or of the surface of the soil are not safe standards on which to base the need for irrigation water.

d. The normal rate of cane growth is resumed quickly after irrigation water is applied unless the period of inadequate soil moisture is sufficient to damage the physical structure of the plant.

e. The cane plant continues to transpire considerable quantities of water even when the soil moisture content is too low to promote active growth.

6. In an attempt to develop a single-value soil constant which could be used to classify soils on the basis of their moisture-holding characteristics, a simple laboratory determination called the moisture equivalent was examined critically:

a. The moisture equivalent appears to be the best available method for the rapid classification of the physical nature of Hawaiian soils.

b. The maximum field capacity is equal to 1.1 times the value of the moisture equivalent on practically all soils examined.

c. A high correlation was found between the moisture equivalent and the permanent wilting percentage, or lower limit of available soil moisture. The moisture equivalent of a soil divided by 1.25 is roughly equal to the wilting percentage of that soil. However, enough exceptions and departures from this generality exist to warrant caution in the use of the moisture equivalent for precise determinations of the lower limit of soil water available for cane growth.

THE WAIALUA IRRIGATION INVESTIGATIONS

By J. A. Swezey

Five years of basic research by the Experiment Station, supported by independent studies of many individual plantations, indicated that fundamental relationships between Hawaiian soils, irrigation water, and the sugar cane plant substantiated in general the results of similar investigations in Europe and Mainland United States. The research demonstrated that soil moisture and cane growth measure-

ments might prove of value in obtaining more efficient irrigation on plantation field areas.

Reasons for the Investigations

The next logical development in the series of investigations was in the application of these scientific tools for irrigation guidance to commercial field practice. This opportunity arose during the latter part of 1932 when Mr. Shaw transferred from the Experiment Station to the Waialua Agricultural Co., Ltd. He was requested by the plantation management to outline a program which would lead toward better control and more efficient use of the plantation water supply. His suggestions included a coordinated plan of water measurement and administration, the classification of plantation soils on the basis of their moisture-holding characteristics, and the application of soil moisture and cane growth measurements to commercial field areas in an effort to obtain more information on the relation of soil water to crop production and to develop a practicable means of applying these data to routine irrigation control.

Purpose of the Investigations

The Experiment Station was sufficiently interested in the possibilities of this form of investigation in relation to the irrigated plantations of the Territory to suggest a cooperative project between the Experiment Station and the plantation. The Director of the Experiment Station outlined the purpose of the project in a letter to the Experiment Station Committee as ". . . a study of means to determine more accurately the interval permissible between irrigations under the several variables of (a) age of crop on the land, (b) climatic conditions for the period in question, and (c) type of soil, etc. At the present time the decision of when and where to place water over a large area is based to a very considerable extent upon human judgment. If we had the knowledge as to where water, when not abundant, could be used most effectively in point of its sugar-producing value, the profits on a large plantation could very probably be increased by hundreds of thousands of dollars in the course of a year. . . . The Waialua plan is a logical sequel to the other work, and it aims to construct a bond leading from our present scientific knowledge to the development of precision in irrigation practice."

The cooperative project was approved, and with Prof. Wadsworth in consultation and the writer in residence on the plantation, the investigations were started in the early spring of 1934. This report deals with the methods developed in classifying the plantation soils on the basis of the moisture equivalent, with a detailed description of methods and results of field studies on the relation of water to crop production from commercial cane areas, and with the application of the procedure developed in the field to plantation irrigation practice.

Classification of Plantation Soils

Laboratory Procedure:

The first phase of the Waialua investigations was the classification of soil types by means of a moisture equivalent survey covering the entire plantation. Since the moisture equivalent served as the basis of classification, the laboratory procedure employed in determining this soil characteristic will be described briefly:

1. The soil sample is air-dried for 24 hours.

2. The soil is then sifted through a 2.0-millimeter screen.

3. Screened soil equivalent to about 30 grams on an oven-dry basis is placed in each of four centrifuge cups.

4. The cups, containing soil, are immersed in distilled water for 24 hours, during which the soil becomes saturated.

5. The cups are then placed in a centrifuge for 30 minutes at 2,440 revolutions per minute, which develops a force equivalent to 1,000 times the force of gravity.

6. The residual moisture contents (oven-dry basis) of the soils in the four cups are averaged. The average per cent moisture is reported as the moisture equivalent of the sample.

Field Procedure:

The field procedure used in making the moisture equivalent survey was conducted as follows:

As soon as possible after the harvesting of each field, two permanent points or a permanent line, such as a railroad, were located and identified on the map of the field, to serve as a base line. From this base line a system of coordinates at 300-foot intervals was developed and drawn on the field map. Each coordinate intersection within the field boundaries was assigned a number. With transit and chain, these points or stations were located in the field, a flag being planted at each station. The base line was referred by horizontal angle to some third point external from its extremities. The mill stack was usually found to be a convenient reference point. This triangulation made it possible to relocate any individual station in the future.

At each station a 2-inch boring was made to a depth of 2 feet and two samples obtained. Each sample was sufficient to fill a one-pound can, one being of all soil to a depth of one foot, the second being from the 1- to 2-foot depth. Field notes on general topography and on soil color and texture were recorded for each sampling station. By this method of sampling, information was acquired for each two acres over the entire area of the plantation.

Results of the Completed Survey:

All soil samples were sent to the Waipio soil laboratory of the Experiment Station, where they were analyzed for moisture equivalent values by the method described above. The data were classified according to the table appearing immediately below:

TABLE IV

CLASSIFICATION OF PLANTATION SOILS BY MOISTURE EQUIVALENT VALUES

Moisture Equivalent Class Per Cent	Predicted Value of— Maximum Field Capacity Per Cent	Predicted Value of— Wilting Percentage Per Cent	Predicted Range of Available Soil Moisture Per Cent
25.0 and less	27.5 and less	21.0 and less	6.5 and less
25.0 to 30.0	27.5 to 33.0	21.0 to 25.0	6.5 to 8.0
30.0 to 32.5	33.0 to 36.0	25.0 to 27.0	8.0 to 9.0
32.5 to 35.0	36.0 to 38.5	27.0 to 29.0	9.0 to 9.5
35.0 to 40.0	38.5 to 44.0	29.0 to 33.5	9.5 to 10.5
40.0 to 45.0	44.0 to 50.0	33.5 to 37.5	10.5 to 12.5
45.0 and over	50.0 and over	37.5 and over	12.5 and over

Predicted maximum field capacities and wilting percentages were computed by the following formulae:

Maximum field capacity = 1.1 × moisture equivalent.

Wilting percentage = moisture equivalent ÷ 1.2.

In the second equation the factor 1.2 is used instead of 1.25 as given previously in this report for the following reasons:

(a) Previous determinations had shown the factor 1.2 to hold for most Oahu residual soils.

(b) Since moisture equivalent was to be used as a general guide, a factor significant to tenths instead of hundredths was sufficiently accurate.

A color symbol was assigned to each moisture equivalent class, and the data for each station were plotted on the field map with color. This initial plotting was later transferred, again with color, to the map of the plantation.

The completed survey has contributed valuable basic information on the variation of soil types over the plantation area. It has demonstrated that the area of the plantation may be divided into definite soil groups determined by their parent material and degree of weathering, each of which has definite characteristics of moisture retention and physical structure. Very briefly, these soil groups may be defined as follows:

Group I—The Mountain Belt extends from the 550-foot contour to the upper limits of the plantation. It is characterized by soils of high moisture-holding capacity, with moisture equivalent values from 35 to 45 per cent, and available soil moisture from 10 to 12 per cent. The soil is deep and uniform as to depth and area.

Group II—The Middle Belt extends from the 300-foot contour to the 550-foot contour. It is characterized by soils of good moisture-holding capacity, with moisture equivalent values from 30 to 35 per cent, and available soil moisture from 8 to 10 per cent. The soil is fairly deep and uniform on plateaus, with rather shallow topsoil and low retentiveness on palis and ridges.

Group III—The Lowland Belt extends from the 100-foot to the 300-foot contours. It is characterized by soils of low moisture-holding capacity, with moisture

equivalent values from 25 to 35 per cent, and available soil moisture from 6.5 to 9.0 per cent. There is evidence of erosion and shallow topsoil throughout, with very low moisture retentiveness on ridges and palis. This belt is marked by heavy rock deposits and diverse soil-type distribution, especially near the older Waianae Range. Apparently it is the upper edge of an alluvial fan.

Group IV—The Coastal Plain extends from sea level to the 100-foot contour. It is characterized by soils of high moisture-holding capacity, with moisture equivalent values from 35 to 45 per cent and greater, and available soil moisture from 10 to 14 per cent. The soils are chiefly alluvial deposits from the uplands and marine deposits from old high-level seas. The soils are of variable depth and uniformity, often broken by old coral beds.

Group V—The Beach Belt is a limited and broken area close to sea level. It is characterized by soils of very low moisture-holding capacity, with moisture equivalent values 25 per cent or less, and available soil moisture 6.5 per cent or less. This belt is chiefly old beach lines and coral outcrops.

It should be understood that this soil classification is not necessarily a reflection of the productivity or fertility of the areas described, but pictures rather sensitively the physical and particularly the moisture characteristics and limitations of the soil. Other things being equal, a soil in Group III might well produce as much or more sugar per acre as a soil in Group I or II, but it would require more frequent applications of water to maintain the same rate of growth.

Field Studies of Plant and Water Relations

Location of Observation Stations:

The object of the next phase of the Waialua investigations was an attempt to learn more precisely, under actual commercial field conditions, the effect of weather variations, soil type, age of cane, and similar factors on the interval permissible between irrigation applications, if uninterrupted cane growth was to be maintained.

The field studies at Waialua of the basic relationships were not experimental in the sense that there was any comparison of treatments. The investigators did not aim to control any factors affecting the development of the 1936 crop, but to observe and record all natural conditions and phenomena attendant upon the development of the crop. It was intended that analysis of these records should form a basis for a future control program.

Six fields for observation were selected in 1934 at key positions, extending from one extremity to the other of the plantation and from sea level to 750 feet elevation, embracing diverse combinations of soil type, elevation, exposure, and cane age, and each representing a considerable area in its district.

Information relative to the locations of these six fields is tabulated below:

Field	Elev. Ft.	Crop Started	Soil Group	Geographical Location	General Comments
Waimea 3	355-410	3/5/34 (Ratoon field)	I	North end of plantation. Rainy region. A mauka field.	Exposed to tradewind on northeast side. Small gulley in northern part of field. Deep ravine in southern part. Water supply at times limited.
Kawailoa 3	180-240	3/22/34 (Plant field)	III	North-central portion of plantation. Region of medium rainfall. A makai or lower middle belt field.	Somewhat shielded by camp on mauka side. South side ends on edge of deep gulch. Irrigation by pump water. Flat, gently sloping surface.
Opaeula 13	590-690	6/14/34 (Ratoon field)	I	East - central portion of plantation. Extreme mauka field.	Exposed on mauka side to northeast tradewind. Flat, medium sloping surface. Irrigation by mountain water, fairly reliable supply.
Helemano 2A	60-190	8/7/34 (Ratoon field)	III	Central part of plantation. A makai field on foot of ridge.	Somewhat shielded from northeast winds by end-sloping of ridge. Surface terraced, with steep pitches in upper portion. Irrigation by pump water.
Mill 2	15-20	4/30/34 (Ratoon field)	IV	West - central part of plantation. Extreme makai field.	Practically level field with slight depression in middle. Irrigation by pump and mill water.
Gay 7	150-250	4/11/34 (Ratoon field)	III	Western portion of plantation. A mauka field for this part of plantation.	Shielded from wind on mauka side, makai side somewhat exposed. Medium, flat slope. Pali in makai side of field. Irrigation by somewhat limited supply of water.

(H 109 cane under contour method of irrigation in all fields)

General Description and Equipment of Observation Stations:

In each of these fields, a location was selected which was considered by the Division and Irrigation Overseers to be an average one relative to water requirement, soil type, and yield ability as based on cane stands of previous crops. It was required that this localized area be on a medium, well-drained slope, with furrows in good condition. Within this area, a line of cane was selected which fulfilled the following specifications:

1. Shoots should be of about equal height.
2. Shoots were uniformly spaced from end to end of the line.
3. The line was 50 feet or more within the field boundary. This line of cane was termed the "Station line."

Detailed information on the average moisture equivalent of the vicinity was obtained by sampling at the locations shown in Fig. 7. Two samples were taken from

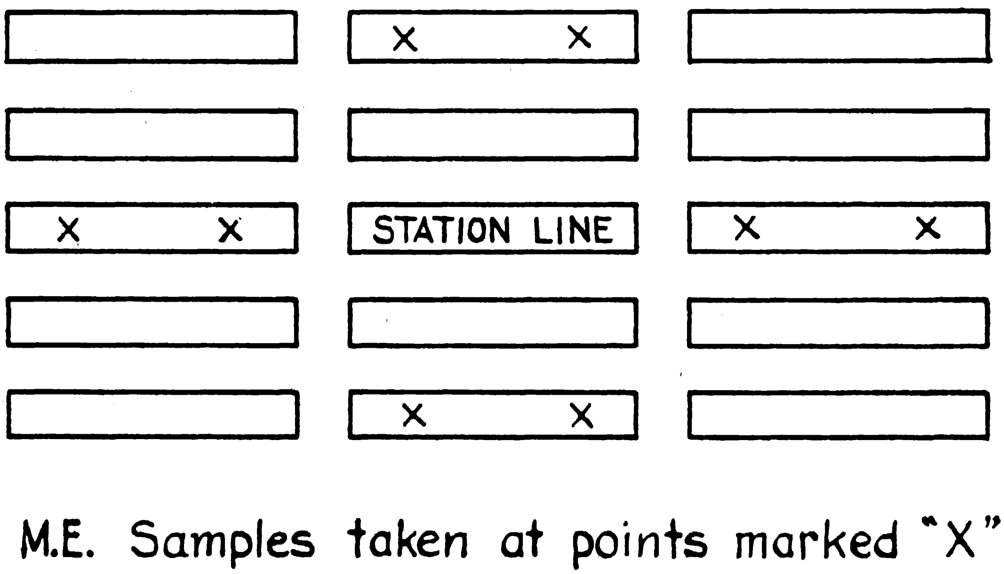


Fig. 7. Plan of vicinity surrounding cane growth and soil moisture observation station, showing location of borings for moisture-equivalent samples used in predicting limits of available soil moisture.

each boring: one from the first foot and one from the second foot. The average moisture equivalent thus obtained was used to predict the maximum field capacity and wilting percentage of the observation station.

On the edge of the field near each observation station the following weather instruments were installed: maximum and minimum thermometers (U. S. Weather Bureau type), and a rain gage. At the Waimea 3, Opaeula 13 and Mill 2 stations, an evaporation pan was also included in the equipment.

Substations were established at two other remotely separated points in each observation field. The selection of locations and of shoots was made in the same manner as for the main station of the field. At these substations only 10 stalks were tagged, and no samples were taken for moisture equivalent analysis.

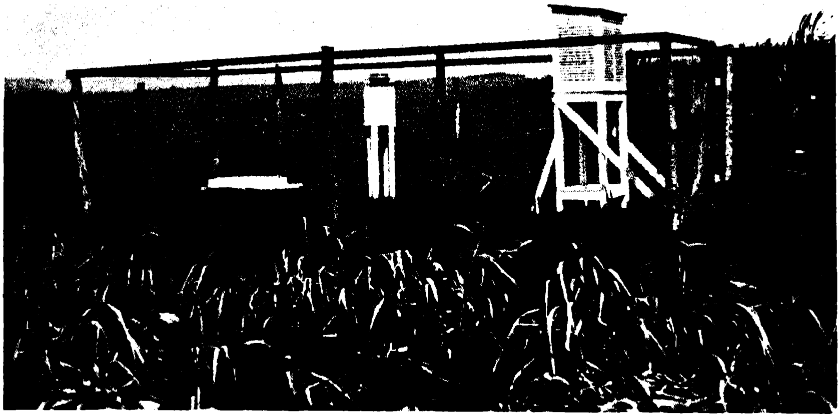


Fig. 8. Typical weather station. Left to right: evaporation pan, rain gage, thermometer shelter. This is the source of weather data for comparison with growth and soil moisture data.

Observation Procedures:

At each of the main stations observations were made daily (except on Sundays and holidays) of the length of each of 20 stalks, soil moisture by sampling the vicinity of the station line, and weather. At the substations weekly observations were made of the lengths of 10 stalks, the purpose of the substations being to obtain a rough comparison of the rate of growth in various parts of the field.

Methods and technique employed in making these observations will be described in this section of the report.

General Procedure: Precautions were taken continually to avoid disturbing the normal condition of the cane. The observers entered and left each station by a different route as much as possible to prevent excessive packing of the soil. The ground was covered with trash to cushion the effects of walking and standing.

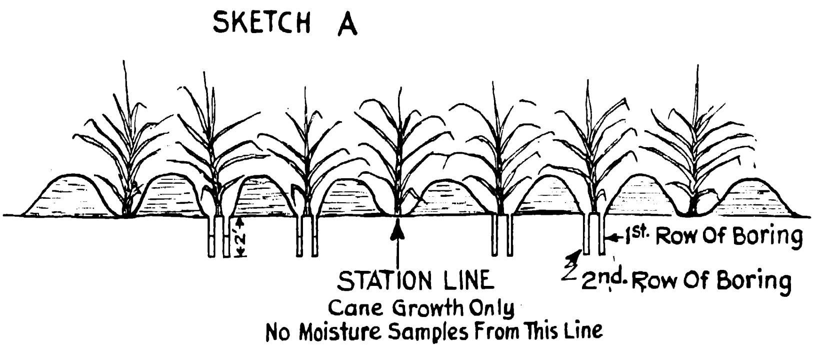
Weather Observations: Standard U. S. Weather Bureau procedure was employed in reading the weather instruments. The observers recorded their personal estimate of the character of the sky ceiling, as well as of direction and approximate strength of wind, and presence of dew.

Technique of Soil Moisture Observations: A description of the technique of observation follows; with, first, a discussion of the soil moisture sampling and determination.

To insure obtaining reliable data in which confidence could be placed, precise specifications were adopted for the procedure of soil moisture observation. These specifications required that exactly the same procedure be followed for each subsequent observation, as a means of reducing accidental errors. Controllable errors were eliminated by proper procedure.

Sampling Methods Used in the Field: A moisture observation was made by boring a hole one or two cane lines mauka of the "station line," and another hole one or two lines makai. This is shown in Fig. 9. The holes for each successive obser-

vation were bored about 8 inches from the last previous observation holes. Thus about three months might elapse before the sampler covered the route shown in Sketch B of Fig. 9. All holes were bored in the bottom of the furrow (Sketch A, Fig. 9). The depth of boring was two feet. One sample was obtained from the first foot and one from the second foot of each hole. Per cent moisture was deter-



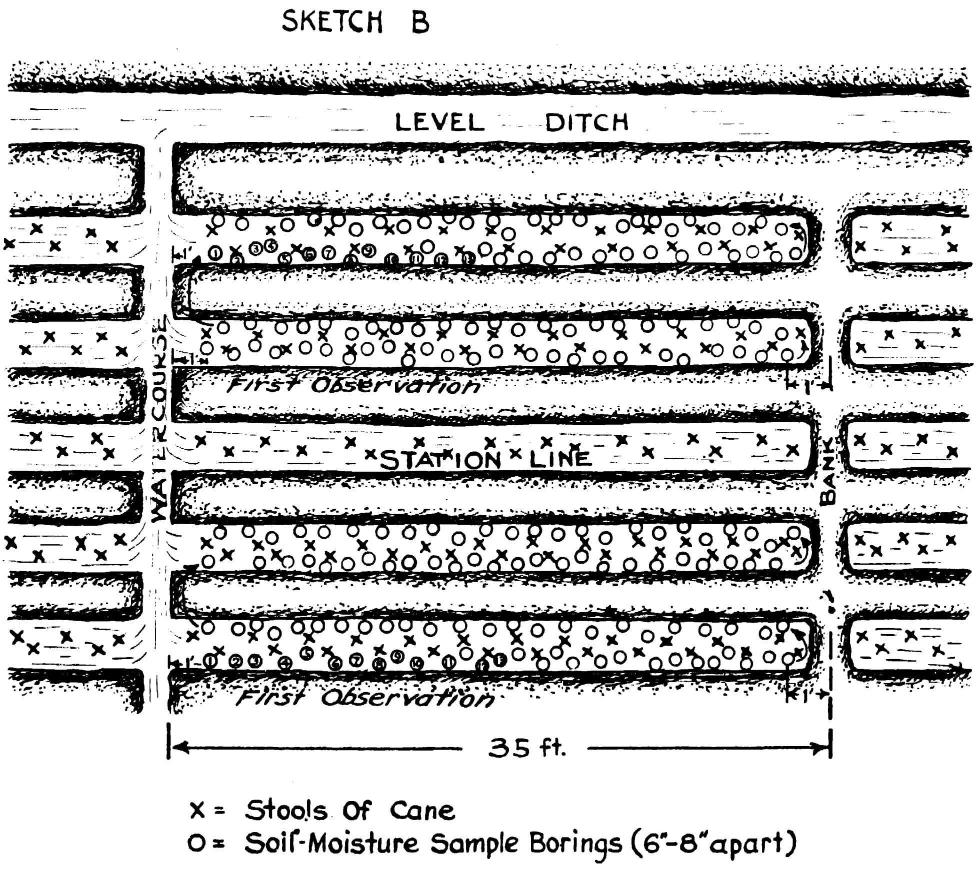


Fig. 9. Sketch A—Location of soil moisture sample borings relative to furrows and cane stools.

Sketch B—Location of soil moisture sample borings relative to measured-stalk line, also showing route followed from day to day by sampler.

mined for each of the four samples constituting the observation. The average per cent moisture was reported for plotting on the graphical records for the Station. The four individual determinations of moisture afforded an indication of the general vertical and lateral distribution of moisture in the area surrounding the line of cane in which stalk elongation was being measured.

Special care was exercised in boring all sample holes. In all cases under normal conditions the first (or top) one to two inches of soil were scraped away from the

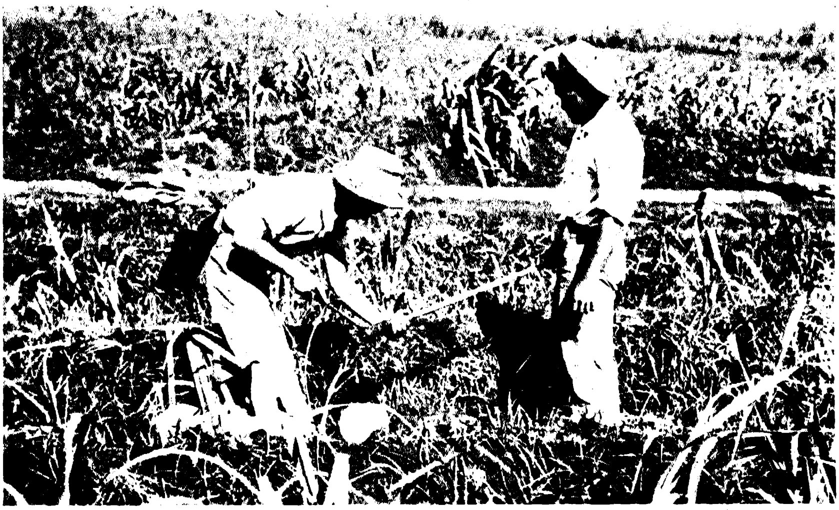


Fig. 10. Moisture sampling. One man can take sample alone, but in big cane, time is saved by working in pairs.

point at which the hole was to be bored. This was done to prevent loose soil, which was subject to drying by evaporation or wetting from light dewfall, from dropping into the hole and thus being mixed with the sample. In removing the auger from the hole, care was taken to avoid scraping the walls of the hole, thus preventing contamination of a sample from the bottom of the hole with soil from the upper horizon. After rainfall of up to one-half inch, approximately, which would penetrate only a few inches and therefore produce an average moisture determination somewhat misleading as to the actual moisture available to the cane, the top 4 to 6 inches of soil were discarded from each boring.

Each sample consisted of portions of soil taken from all parts of a well-mixed pile. The soil was placed loosely in an eight-ounce, airtight can. The unused remainder of each pile of soil was returned to the hole and tamped tight. This prevented seriously altering the condition of the field in the vicinity of the station. The soil and the cans containing soil were protected from exposure to the sun and wind. Can numbers were recorded as soon as the samples were placed in these containers. Can markings were renewed frequently to avoid illegibility. These precautions assisted in producing reliable results.

Laboratory Equipment and Procedure for Moisture Determination: The moisture content of the soil samples was determined in the laboratory by the following procedure:

For all moisture determinations made during these investigations, weighing was accomplished with a torsion balance, sensitive to 1/10 gram. Weights used were of the analytical type. The ovens for drying soil were provided with thermostatic temperature control.

All of the sample brought from the field in the sample can was used for the moisture determination. The usual amount of wet soil put through this determination was 100 to 130 grams. All sample cans were tared to equal weight with solder which facilitated weighing and simplified calculations, as the sample was weighed and dried in the sample can and the tare weight of the can was balanced by a counterweight. The can weights were checked from time to time and necessary adjustments made to maintain the tare. The samples were dried in the oven from 22 to 24 hours at 100° to 105° C. Per cent moisture was expressed on an oven-dry basis.

Very soon after commencement of observations in 1934, several tests were made to ascertain the advisability or necessity of incorporating certain other standards in the general technique. Results of these tests showed the following:

(a) The sample could be exposed to the air, by removing the lid from the sample can, for well over 5 minutes without any significant loss of moisture, due to the relatively large bulk of the sample. Thus, haste and error could be avoided, since only 1 or 2 minutes of exposure were required in obtaining the wet weight.

(b) It was an unnecessary waste of time to cool the samples in a desiccator, as is usually done in laboratory practice, before obtaining the dry weight.

(c) Constant dry weight could be obtained in 20 to 24 hours of drying. It was satisfactorily proven that 48 hours of drying was unnecessary. Other frequently repeated tests checked the uniformity of drying conditions throughout the oven.

Toward the end of the observations of the 1936 crop, plans were made for the practical application of the results of this investigation. The program involved a heavy schedule of daily observations with a correspondingly large number of moisture determinations. Furthermore, it was desired that the per cent moistures of each day's samples should be reported at 8:00 a. m. the following day. This meant that the time required for moisture determination must be materially reduced. Such a time reduction could be effected by decreasing the manual operations, as well as by shortening the time of drying.

Acceleration of the manual operations was obtained by purchasing a self-reading scale and by using shallow, rectangular trays for the drying of the soil. These trays were tared to equal weight, which was checked and adjusted each month. The scale is a self-reading type similar to the butcher's or delicatessen's but calibrated in grams and specially equipped with an extra-length counterpoise beam. The beam is designed so that the counterpoise can be set to back-weigh or tare in multiples of 50.0 grams. Less than 50.0 grams can be read on the indicator chart to an accuracy of 0.1 gram. The beam is fitted at its extremity with a special pan, hung on a ball bearing, on which the soil moisture tray is placed for weighing. (See Fig. 11.) Weighing of wet or dry soil is a very simple rapid procedure in which all calculations are eliminated by the use of a conversion table. The whole process of determining per cent moisture is described as follows:

The scale counterpoise is set at the proper point on the beam to balance the tare weight of the moisture tray. Exactly 100.0 grams of the wet sample are placed in

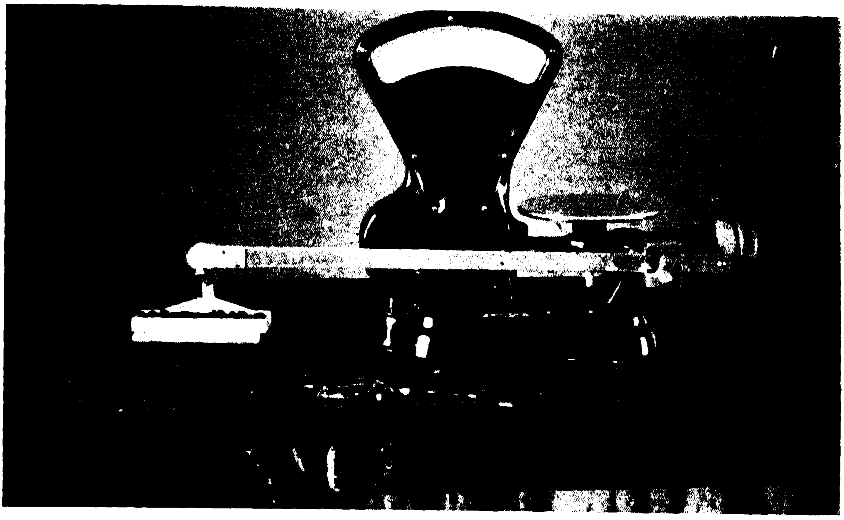


Fig. 11. Self-reading, specially designed scale used in laboratory determination of soil moisture developed during this investigation.

the tray, as checked by reading the indicator chart. When the wet weight of all samples is thus obtained, the trays are placed in the oven, eight on each shelf, and dried for 16 or more hours at 105° C. Dry weights are then obtained for each sample. These are the only weights the analyst is required to record. No calculations are necessary as the dry weights are changed to per cent moisture content by the conversion table, a portion of which appears below. As an example it is seen that a sample, having a dry weight of 24.3 grams, originally contained 34.6 per cent moisture.

CONVERSION TABLE FOR SOIL MOISTURE DETERMINATION

Scale Chart Reading (with dry soil on scale)	Per Cent Soil Moisture
24.6	34.0
24.5	34.2
24.4	34.4
24.3	34.6
24.2	34.8
24.1	35.0
24.0	35.1

Appropriate tests were made to determine the 16 hours at 105° C. as being the correct time for drying with the new type of tray. Other tests indicated that the slightly greater number of samples in the oven did not impair the uniformity of drying conditions throughout the oven.

This new type of equipment developed for the extensive soil moisture program at Waialua plantation offers several desirable features. These are a slight increase possible in oven load, decrease in time required for drying, and a decrease in time for the manual operation of weighing. Several tests indicated that the manual operations with the new equipment require, conservatively, one hour and 12 minutes less for weighing 100 samples than did the original equipment used for the investigations. It is to be emphasized that both types of equipment are available and that both give equal accuracy of results.

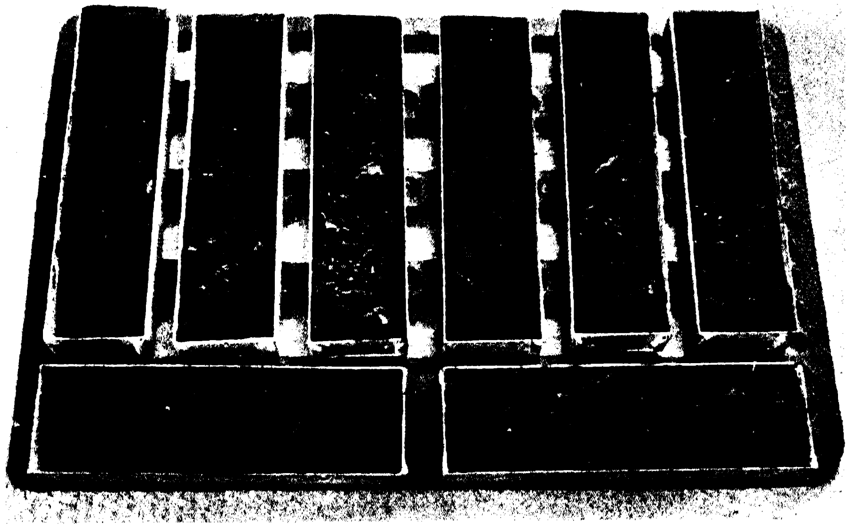


Fig. 12. New type of moisture trays as placed on oven shelf. Procedure developed during this investigation.

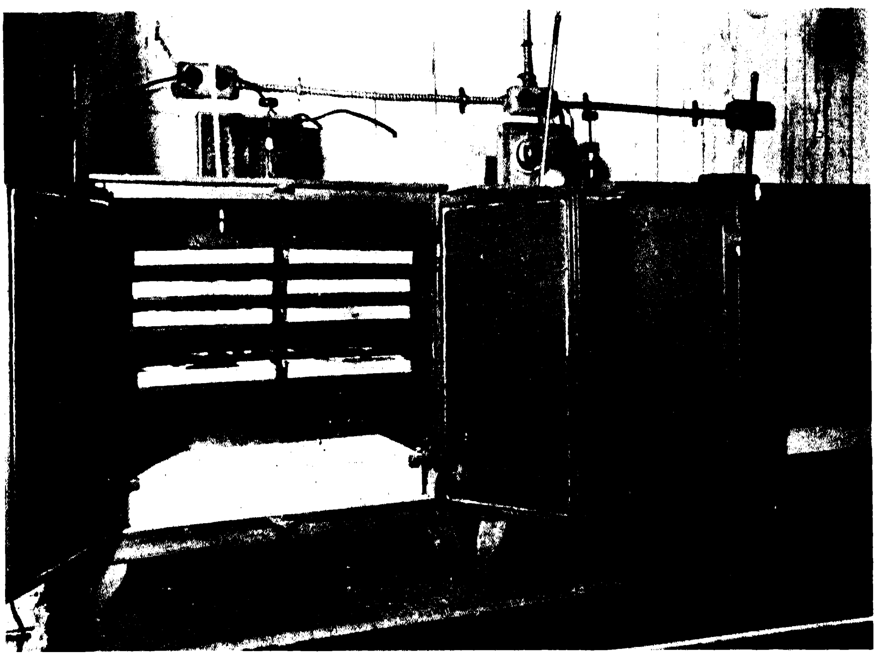


Fig. 13. Oven loaded with 6 shelves, each holding 8 trays. Ready to start 16 hours of drying at 105° C. according to new method.

Technique of Cane Measurement: Simultaneously with the moisture sampling, observations were made of the length of each of the 20 stalks at the station, and the average length obtained. The method of selecting these stalks has been mentioned, and it was stated that each was permanently identified by a number tag. At each successive observation the same stalks were measured, and precise and perfectly comparable records of stalk elongation were obtained. If an entirely new set of stalks had been measured at each visit, the average lengths would have fluctuated

from day to day and no continuity would have been possible in a curve of average lengths plotted against elapsed time.

The method of measuring the length of a single stalk is more or less a standard procedure, but it is advisable at this point to describe the process as applied in the Waialua investigations.

The length of each stalk was observed by the following method:

A large (10-penny) nail was driven into the ground at the base of each stalk shoot, the head of the nail being left about one-half inch above ground surface, so as to be clear of later-deposited silt. These nails served for some months as "zero" datum points.

A steel tape, one meter long and graduated in centimeters and tenths of centimeters, was used for measuring the stalks. Measurements were made by metric scale, since the 0.1 cm. graduations are smaller and make it more precise and convenient than the English units. Readings in centimeters were converted to inches or feet when desired. The stalk length was measured from the head of the datum nail to the top edge of the highest visible leaf ligule ("dewlap" or "transverse mark"). (See Fig. 14.) Note that as soon as the ligule mark on leaf "B" appeared between leaves "A" and "C" the point of measurement was shifted from the ligule on leaf "A" to the ligule on leaf "B." As the shoots grew longer, wind and the cane's weight combined to produce curvature of the stalks. Care was taken, in measuring such stalks, to make the tape follow the curves closely and along the same side of the stalk at each observation.

When from one to two meters of stalk were formed, a datum mark was made on the hard rind below the lowest adhering leaf. (See Fig. 14.) With each additional gain of sufficient millable stalk, a new datum mark was made in the same way. Thus, for any observation of stalk length, it was possible to save time and effort by measuring the distance from the highest datum mark to the last ligule. The height of the datum above ground having been recorded, the sum of the two distances was the length of stalk.

The principal object of the growth measurements was to obtain a curve of average lengths against time, the slope of which measured the growth rate of the cane. It was desired by means of this curve to detect the critical points at which the growth rate changed. Furthermore, the observers were interested, first, in the rates of growth between two consecutive irrigations, and second, in the progress of those stalks which would survive to harvest. Hence, if a stalk began to show evidence of being a weakling, very soon to die, it was replaced by a more healthy-appearing stalk. Broken or otherwise damaged stalks were replaced as soon as the injury was discovered. Tasseling caused some disturbance, in that just prior to emergence of the tassel the leaf bundle increases tremendously in length, raising the last ligule abnormally, within only one or two days. After tasseling, the stalk ceased to grow. Tasseling stalks were replaced immediately.

Methods of Recording and Plotting Data: As soon as possible after the observers returned to the office, the data in the field notebook (Fig. 16) were transferred to a daily ledger. Information on this ledger was then plotted immediately on a large scale chart. The data plotted were:

1. Average length of 20 stalks.
2. Per cent soil moisture. (Average of four determinations.)
3. Rainfall.
4. Day-degrees (maximum temperature minus 70° F.).

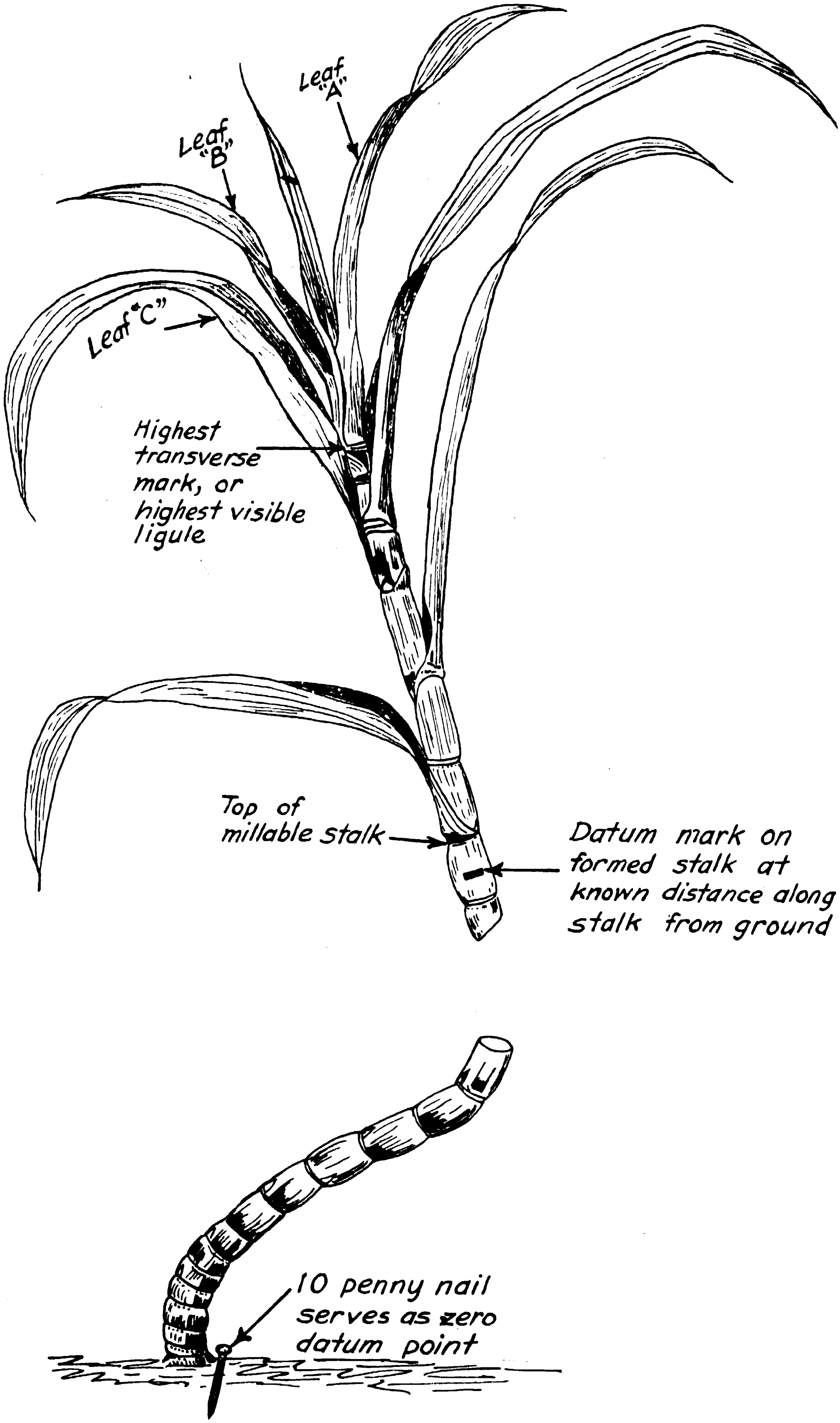


Fig. 14. Cane stalks showing points of measurement.

Fig. 15. Measuring young cane. "O" end of tape held on head of datum nail.

A second ledger was maintained on which were posted monthly totals of growth, rainfall, day-degrees and other information. It summarized concisely the progress of the crop.

Posting and plotting the observed data within a few hours of obtaining it were found to be of inestimable value in knowing and analyzing the conditions which prevailed from one day to the next in the vicinity of each observation station.

Results of Investigation

Plant and Water Relationships:

Earlier studies described in this report demonstrated that cane growth is independent of soil moisture content above a critical value inherently characteristic of soil type.

Relation of Cane Growth to Maximum Field Capacity and Wilting Percentage: Within a few months after commencement of observations at Waialua the charts and data began to show evidence that there existed in commercially operated fields the same relationships between soil moisture and cane growth as were established under carefully controlled conditions in the earlier studies. The present evidence is seen in a typical portion of the chart (Fig. 17), which was selected more or less at random from the large number produced during two years of study at six stations. This

5^{45} a.m.

Sta. No. H-1 (Hele.2-A) Date 4/18/36

Stalk No	L	Stalk No	L	Stalk No	L
1	319.0	11	352.0		
2	214.5	12	331.9		
3	335.0	13	356.1		
4	175.5	14	210.9	Total	Datum
5	278.0	15	226.5	Height	
6	314.2	16	352.2		
7	83.5	17	217.5	= 3241.7	
8	325.5	18	304.5		
9	372.0	19	308.0		
10	329.5	20	263.0		
Total			8911.0		
Aver.			445.6		

Can No.	% Moisture	Can No.	% Moisture
51	34.9	67	35.8
52	34.1	466	33.7
Aver			34.6

Rain .02	Max T 81	Min T 60	° Day 11

Evaporation Gauge

St. −.17	Rd. −.34	Dif. +.17	Evap. In. .19

REMARKS: Clear, No Wind

Fig. 16. Facsimile page from field observation book, showing data taken in fields, and completed in office.

chart is practically self-explanatory, but there are several points to be called particularly to the reader's attention:

The moisture equivalent of the soil at each station was used to predict the maximum field capacity and the wilting percentage. These values were plotted as con-

tinuous lines in the upper part of the chart. These were the predicted limits of soil moisture available to the cane plant. Daily soil moisture contents were plotted on the same coordinates.

In the lower portion of the chart the average length of stalk was plotted, forming a curve. The slope of this curve at any point measures the rate of growth of the cane. The arrows indicate dates of irrigation.

Notice that on the dates of irrigation the soil moisture rises to about the predicted maximum field capacity. The cane plant depleted the soil moisture at about a constant rate to the predicted wilting percentage. The rate of depletion then decreased decidedly until the next irrigation, when moisture was replenished to the maximum field capacity. Evidently, when the cane roots had extracted moisture to the wilting percentage they encountered difficulty in obtaining any more moisture from the soil and consequently there was very little, if any, further depletion. Very appar-

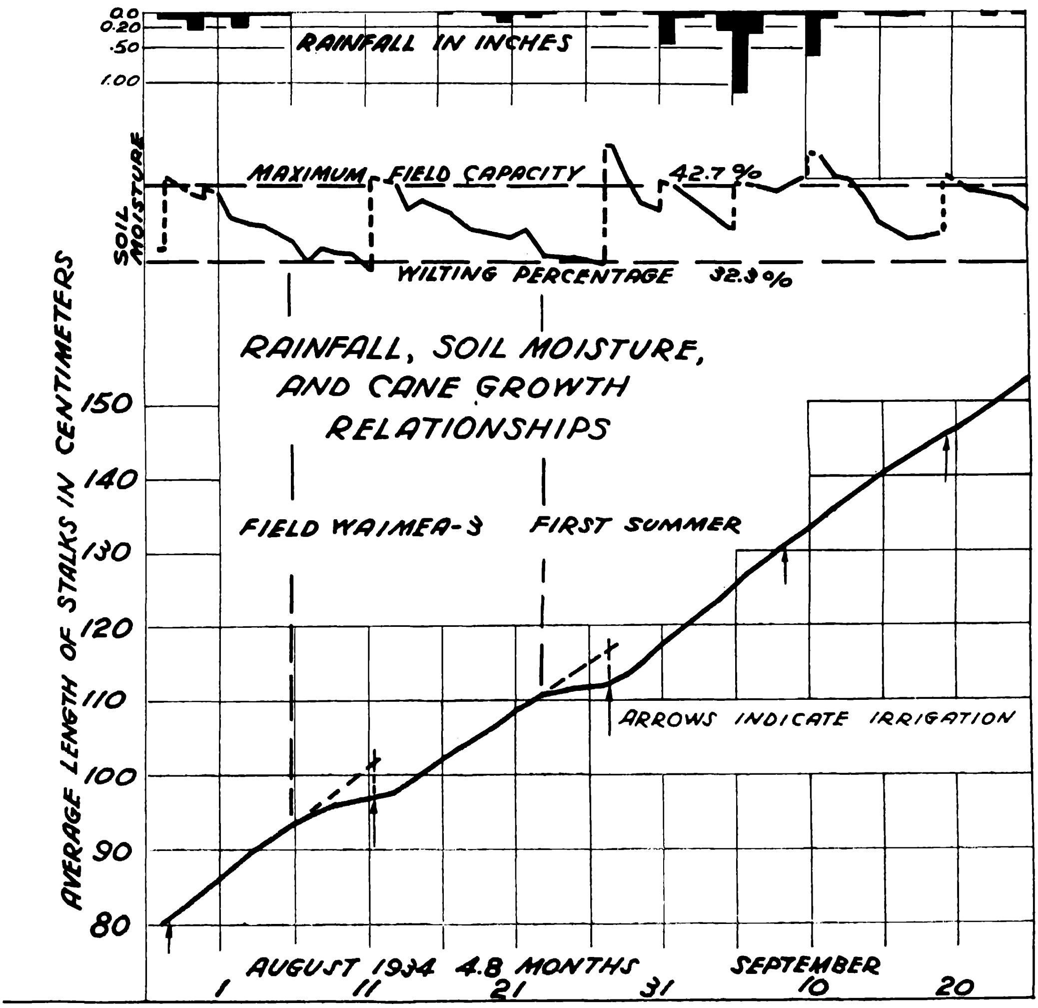


Fig. 17. First summer growth and soil moisture history shows constant rate of growth with ample soil moisture, depressed rate of growth with inadequate moisture, and effect of heavy rain in replenishing soil reservoir. Significance of depressed growth due to inadequate soil moisture is shown by indicating amount of growth which might have been made had irrigation been applied when moisture reached wilting percentage.

ently the wilting percentage constituted a lower limit to the soil moisture readily available to the cane plant.

Substantiation of Soil Moisture Philosophy as Previously Established Under Controlled Conditions: The growth curve appearing in Fig. 17 shows definite responses of the cane plant to soil moisture conditions which provide a reasonably conclusive proof of the philosophy discussed above. It can be seen that after irrigation the curve of average length was a straight line, indicating a constant rate of growth. A critical point on the growth curve was reached where the slope changed and became flatter, indicating retardation in the rate of growth. Notice the very significant fact that the date of this critical point approximately coincided with the date on which the soil moisture was depleted to the wilting percentage. Beyond this date the cane roots were unable to extract moisture readily from the soil, and the result is seen on both curves. The moisture depletion was materially reduced, or stopped altogether, and the rate of growth was depressed. When the next irrigation was applied, the moisture rose to the maximum field capacity. With soil moisture again available to the roots the plant resumed a rapid, constant rate of growth.

The philosophy of the interrelation of cane growth and soil moisture as discussed above and demonstrated many times by observed phenomena may be expressed briefly as follows:

1. As long as soil moisture is above the wilting percentage, the lower limit of availability to the plant, stalk elongation will proceed at a constant rate which is independent of the amount of moisture above the wilting percentage, but is dependent on weather conditions, age of the cane, season of the year, or a combination of factors. Soil moisture is also correspondingly depleted at about a constant rate.

2. When soil moisture is depleted to the wilting percentage, it becomes inadequately available for the plant to maintain a normal rate of growth. Growth is depressed as long as moisture is insufficient.

3. When the soil moisture is replenished above the wilting percentage, cane growth resumes a rapid constant rate dependent on conditions other than the amount of available moisture.

The transitions in growth rates on the average length curve were not always sharp or abrupt changes, depending apparently on the extent of the root system. The root system seemed also to have some influence on the degree of growth retardation accompanying periods of inadequate soil moisture.

Rainfall is seen on the chart to have increased the amount of moisture in the soil, depending on the amount of rain received. After the rain stopped, depletion of moisture proceeded at the same rate as before the rain. Light showers appear to have prevented a severe reduction in rate of growth, during some periods of inadequate soil moisture, although they were not effectual in replenishing the soil reservoir.

Verification by Cane Growth Checks of Wilting Percentages Predicted from Moisture Equivalent: Table V shows the observed percentages of moisture coincidental to critical points of change from rapid to slow cane growth, due unquestionably to insufficient soil moisture. Comparison with the predicted wilting percentages, shows that for the majority of Waialua soils the wilting percentage can be predicted from the moisture equivalent with reasonable reliability. A ratio of 1.20, rather than the general figure of 1.25 mentioned previously in this report, was used as being more indicative of Oahu residual soils.

TABLE V

COMPARISON OF OBSERVED WILTING PERCENTAGES AGAINST PREDICTED WILTING PERCENTAGES AT WAIALUA

		Field Waimea 3		Field Kawailoa 3		Field Gay 7	
Moisture Equivalent			38.8		33.3		33.5
Predicted Wilting Percentage = M.E. ÷ 1.20 =			32.8		27.8		27.9
Observed Wilting Percentages							
Year	Month	Date	% Soil Moisture	Date	% Soil Moisture	Date	% Soil Moisture
1934	May			23	29.4		
	June	14	32.9	13	27.5		
				22	29.7	22	27.8
	July	2	35.3	7	27.0	12	27.8
		20	34.3	16	28.8	21	28.5
				26	27.0		
	August	7	32.3	4	27.0	8	27.0
		23	33.2	13	27.3	29	25.2
				28	24.7		
	September			14	27.4	16	27.5
				26	29.1		
	October	1	34.5	8	28.3	5	27.8
	November			3	29.3	5	26.7
						24	29.7
	December			12	28.0	18	27.0
1935	February	14	34.1				
	April			11	29.1		
				27	27.2		
	May			13	27.5	1	25.4
				24	28.3	23	25.4
	June	13	33.4	9	27.5	7	29.2
				22	27.5	22	28.7
	July	27	32.8	5	28.6	20	26.6
				22	27.9		
	August			15	27.5	3	26.8
				17	28.9	19	28.0
	September					11	30.8
						25	28.6
	October	3	32.8			10	29.8
Average Observed Wilting Percentage			33.5±0.20		27.9±0.15		27.7±0.23
Divergence from Predicted Wilting Percentage			+1.2		+0.1		—0.2

COMPARISON OF OBSERVED WILTING PERCENTAGES AGAINST PREDICTED WILTING PERCENTAGES AT WAIALUA

		Field Mill 2		Field Helemano 2-A		Field Opaeula 13	
Moisture Equivalent			36.1		35.3		41.8
Predicted Wilting Percentage = M.E. ÷ 1.20 =			30.0		29.4		34.8
Observed Wilting Percentages							
Year	Month	Date	% Soil Moisture	Date	% Soil Moisture	Date	% Soil Moisture
1934	July	28	32.4				
	August	7	31.6			9	34.6
	September	23	32.0			12	33.4
						29	36.6
	October	10	31.1	10	29.9	17	33.5
	November	8	32.0				
	December			14	29.9		
1935	April	27	30.0				
	May			23	29.2	4	34.9
	June	12	30.3	19	28.1		
	July			20	31.5	30	35.1
	August	26	31.6	3	30.4	15	33.4
	October			8	31.2		
	December			1	31.1		
1936	June			5	27.6		
Average Observed Wilting Percentage			31.4±0.20		29.9±0.31		34.5±0.23
Divergence from Predicted Wilting Percentage			+1.4		+0.5		−0.3

Suggested Use of Soil Moisture in Determining Proper Irrigation Interval: The practical application of the fundamental relationships between cane growth and soil moisture as observed in this investigation lies in the fact that if it is desired to keep the cane growing without any cessation which might be ascribed to inadequacy of soil moisture, then it is necessary to irrigate on or slightly before the date on which the soil moisture is depleted to the wilting percentage. Referring now to Fig. 17, the proper irrigation interval would be the number of days elapsing between an irrigation and the date on which the growth rate begins to decrease, soil moisture being coincidentally at the wilting percentage.

How is the proper interval to be readily determined? First it is necessary to establish the value of the wilting percentage at the location in question. Then, any series of soil moisture observations can be extrapolated to predict the day on which the wilting percentage probably will be reached. Cane growth observations, alone, will not serve to indicate or predict the proper date on which to irrigate, but merely indicate that the wilting percentage has already been reached. A study of cane growth together with soil moisture observations serves as a check or aid in establishing the wilting percentage. Using cane growth observations solely as a guide, might result in several days' delay in irrigation on every round. A program of soil moisture sampling will produce the desired information as to proper or necessary interval; but this program should be supplemented by cane growth observations.

Winter Conditions:

This is an opportune point at which to call attention to winter conditions as related to soil moisture, cane growth, and proper or required irrigation interval. Fig. 18 shows a large portion of the first winter season in Field Waimea 3. Briefly, the following are the significant points of interest:

1. There was continuous, rather heavy rainfall throughout November 1934, and again from the middle of December 1934 to the middle of January 1935. Due to this rainfall, soil moisture was maintained at a high level for approximately 3 months. The effect of the rain continued for 15 days in February, when dry weather prevailed.

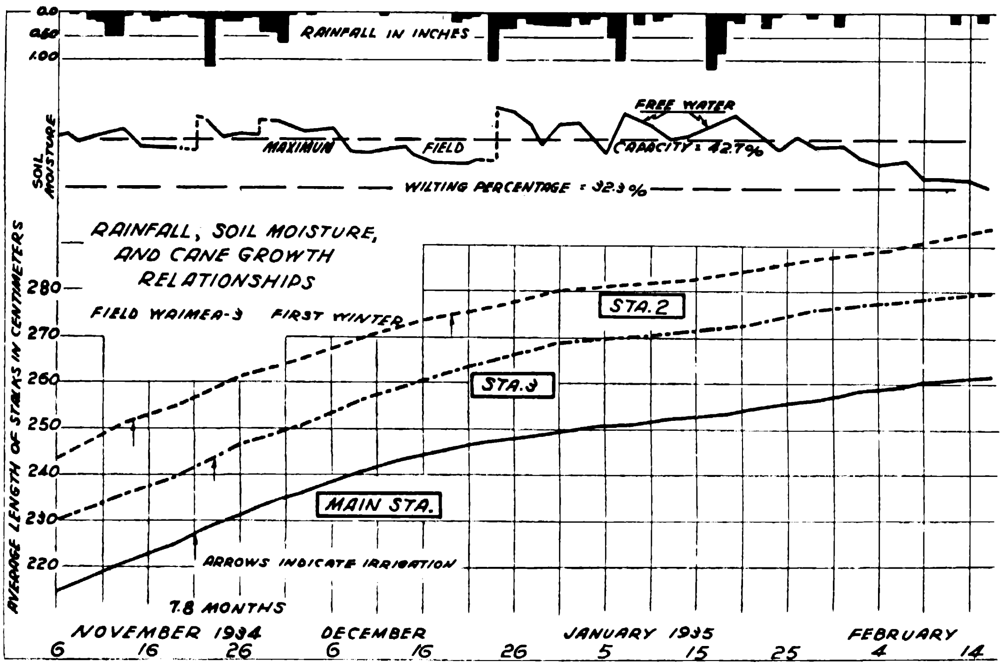


Fig. 18. No irrigation needed during continuous rainy weather which maintains high level of soil moisture. Sometimes irrigation is applied unnecessarily.

2. Most important to note is that throughout the entire period of the chart no irrigation was necessary. The irrigation on November 21 was unnecessary, as moisture in the soil at the time was ample. Even without advance knowledge as to the heavy rain which occurred two days later, the moisture curve indicated irrigation should not have been necessary for at least another 7 to 10 days, with dry weather prevailing. The moisture curve during the dry weather from January 25 to February 14 indicates that at the prevailing rate of depletion an irrigation should be applied on February 16. This is the first irrigation that was necessary after the application made on November 5.

3. This chart shows that, with an established program of soil moisture observations as a guide, it should be possible to irrigate much less frequently during the winter when rainfall maintains soil moisture more amply than is usually accredited to it.

On Fig. 18 are plotted growth curves of the substations in Field Waimea 3. The rates of growth during this period were about the same as the rate at the main station. This was found to be true, in general, in the other five fields throughout the crop. Apparently the single main stations indicated satisfactorily the progress of the crop for their respective fields.

Long-Period Curves:

Attention has been called in Fig. 17 to a number of times when soil moisture was depleted to the wilting percentage, and remained at or below that limit for several days with concurrent reductions in rate of growth. It was also mentioned that if it be desired to keep the cane growing without cessation, irrigation should be applied on the date when soil moisture reached the wilting percentage. Inability to irrigate until after the proper date, due to any of a number of causes, results in a loss of potential cane, as can be shown by the following example:

Example of Potential Cane Lost Due to Inadequate Soil Moisture: At the station in Field Waimea 3, soil moisture was about at the wilting percentage on August 6, 1935. (See Fig. 17.) The cane growth curve shows a critical point on this date, after which the growth rate was markedly depressed. When irrigation was applied on August 11, growth was resumed at about the same rate as had prevailed prior to August 6. If it had been possible to irrigate on August 6 instead of on August 11, it may be assumed with confidence that the growth would have proceded after the sixth at the same rate as between July 28, the date of the previous irrigation, and August 6. This is indicated on the chart by a dotted extension of the July 28 to August 6 growth curve. It is seen, then, that the average length of stalk would have been 101.6 cm. on August 11 instead of the 97.1 cm. it actually was on that date. In other words, by a properly timed irrigation it would have been possible to avoid a loss of potential cane stalk equivalent to 101.6 — 97.1 = 4.5 cm. = 1.8 inches. By this graphical method of extrapolation, a record was tabulated of "possible growth," potentially obtainable by properly timed irrigations, against the "actual growth" for the entire crop at each observation station.

Indication by Curves of Total Potential Cane Lost During Crop: During the months of June, July, August, September, and part of October, when growth proceeds at high rates, the increments of lost potential growth may appear to be small individually, but collectively they can be of great economic importance. This is shown by plotting curves of accumulated possible and actual growth (Fig. 19). On this chart the "total loss of cane" is a summation of the increments of potential growth lost throughout the crop.

Seasonal and Age Effects: The long-period curves, Fig. 19, indicate several additional points. It appears that during the first winter season, December 1934 and January and February of 1935, the rate of cane growth was essentially the same in the six fields regardless of age of cane or elevation. Kawailoa 3, the plant field, is a notable exception possibly due to inherent vigor characteristic of plant cane but lacking in ratoons. Likewise, there appear to be no significant differences in second-summer (1935) growth due to age. An interesting exception to this observation was Opaeula 13 which was started in June of 1934. This field is located at 600 to 690 feet elevation. During the summer of 1935 it produced considerably greater stalk

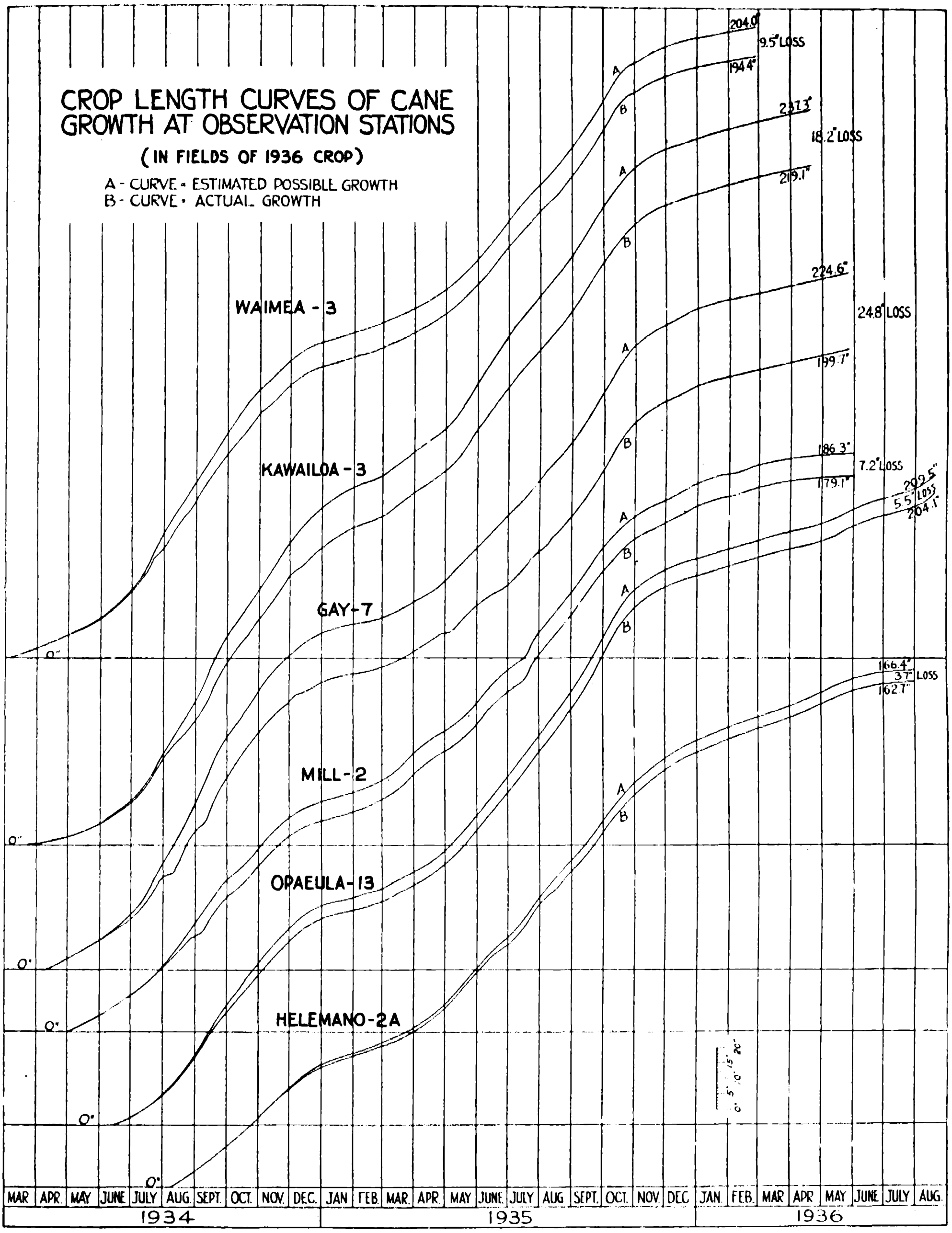


Fig. 19. Graphical crop histories showing difference between actual length of cane yielded, and amount possible with properly timed irrigations. Seasonal and age defects are seen.

elongation than the other five fields. If there is any effect of starting time to be noted from the growth records of these six fields, it would appear that for a late-started field, such as Helemano 2-A, which was started the first week in August 1934, the rate of growth could not attain as great a magnitude before the winter influence became effective. The amount of growth made by Helemano 2-A during August, September, and October of 1934 fell short of the growth made during the same months by the early-started fields. Production in a field started later than

June would appear to be dominated by two winter seasons and only one summer, whereas the earlier-started fields would be able to take advantage of two summers in addition to two winters.

Value of Rainfall as Irrigation:

Natural precipitation is a factor impossible to predict and difficult to evaluate in irrigation investigations and in commercial agriculture. Many investigators have chosen to avoid the complex problems which are presented by the variations in duration and intensity of natural rainfall. Estimates by various investigators on the effective value of rainfall range from 10 per cent to 50 per cent of the total precipitation.

Difficulty of Evaluation Because of Varying Factors: The residual moisture content of the soil before the rain occurs, the soil's capacity for water, the stage of crop development as it influences surface runoff and leaf and trash interception, and the rate of transpiration are all factors to be considered in addition to the duration and intensity of rainfall in evaluating rain as an irrigation.

Consideration of Dominant Factors: Of these factors, the residual soil moisture prior to rainfall, the soil's capacity for water, and the amount of rain received are dominant and can be measured by observation. Opinion based on observation will serve to judge the influence of duration and intensity of precipitation on these dominating measurable factors.

Light Showers Partially Effective for Growth, Ineffective for Soil Moisture: The investigations described in previous sections of this report emphasize the fact that rainfall or irrigation water added to the soil surface increases the moisture content of each increment of soil to its maximum field capacity before any water is added to lower soil increments. It follows that precipitation in an amount less than necessary to fill the entire root zone to capacity will succeed in wetting only the surface layers of soil without raising the soil moisture content of the lower root zone. Thus in a uniform soil with a residual moisture content of 5.0 per cent below its maximum field capacity, a rain of 1.00 inch might penetrate the soil to a depth of approximately 16 inches, while a rainfall of 1.50 inches would be required to wet the soil completely to a depth of 24 inches. In the same soil with a residual moisture content of 9.0 per cent below maximum field capacity, on the other hand, a 1.00-inch rain would penetrate only 9 inches, the 1.50-inch rainfall would penetrate only 14 inches, and to fill completely the 24-inch root zone, 2.75 inches of rainfall would be required.

A study of the soil moisture and rainfall records of the Waialua investigation indicates that rainfall under 0.4- to 0.5-inch is ineffective as an irrigation. At best it appears that 0.25- to 0.50-inch of rain is equivalent to but one day of interval. Although light showers from 0.10- to 0.40-inch appeared to have maintained partially normal growth during periods of inadequate soil moisture, they did not replenish the soil reservoir perceptibly.

Soil Moisture Program Preferable to Formula in Accounting for Rain: We would hesitate to offer a formula for expressing the effective value of rainfall based on the data obtained at Waialua. Such an equation would be so general as to have little use in specific cases or under localized conditions elsewhere. If all factors

were taken into account in formulating the equation, it would then become too cumbersome for easy, universal application.

We prefer to suggest that a program of soil moisture sampling will provide information as to soil moisture contents both before and after rainfall as well as the general prevailing trend of moisture depletion. With no deliberate attempt to evaluate the rainfall, a judicious interpretation of the soil moisture data will provide an index of the proper date for the next irrigation.

Effect of Temperature on Cane Growth: The maximum and minimum themometers, situated adjacent to the observation stations, provided extensive data on temperatures throughout the crop. Since Das has shown, in studies at Pepeekeo and

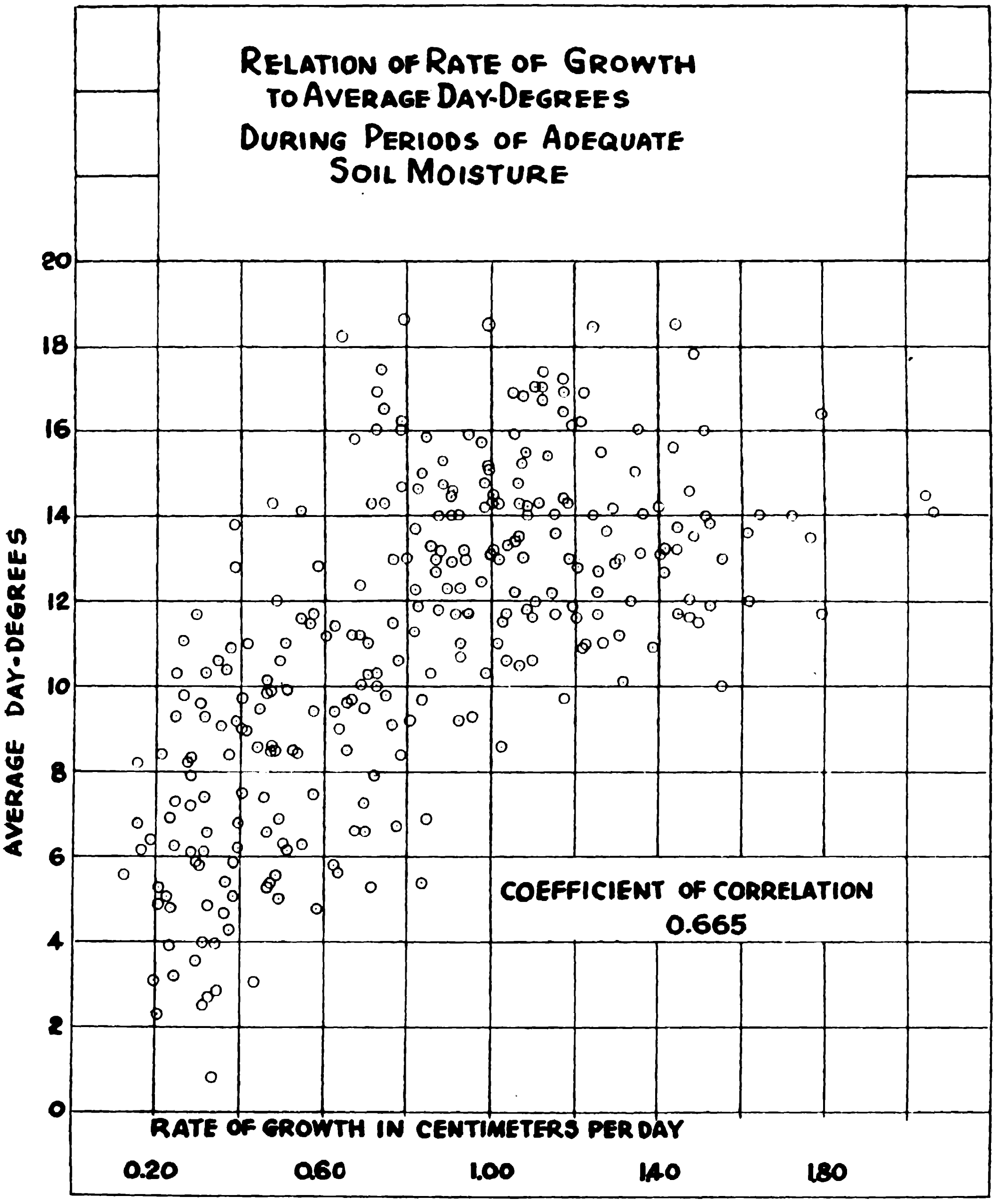


Fig. 20. A gross relationship exists between rate of growth and average day-degrees during periods of adequate soil moisture. Among individual observations there is a wide variation.

elsewhere, a high degree of correlation between growth and temperature, it was believed the Waialua data might show the following relationships:

1. A definite quantitative factor, consistent in value throughout the crop, between growth and day-degrees. This factor would be of great assistance in crop estimation.

2. A similar definite, consistent, quantitative factor between the rate of soil moisture depletion and day-degrees. This factor would be a valuable aid in determining proper irrigation intervals.

Gross Relationship for Entire Crop: All the data on growth and day-degrees at Waialua which have been analyzed are from periods of ample soil moisture, thus eliminating the complicating effect of inadequate moisture. The data show that there is a gross relationship between cane growth and day-degrees over the period of the entire crop. Table VI shows coefficients of correlation for growth against day-degrees. In general the same high degree of correlation found by Das is shown by the data. The relationship is shown graphically by plotting these observations

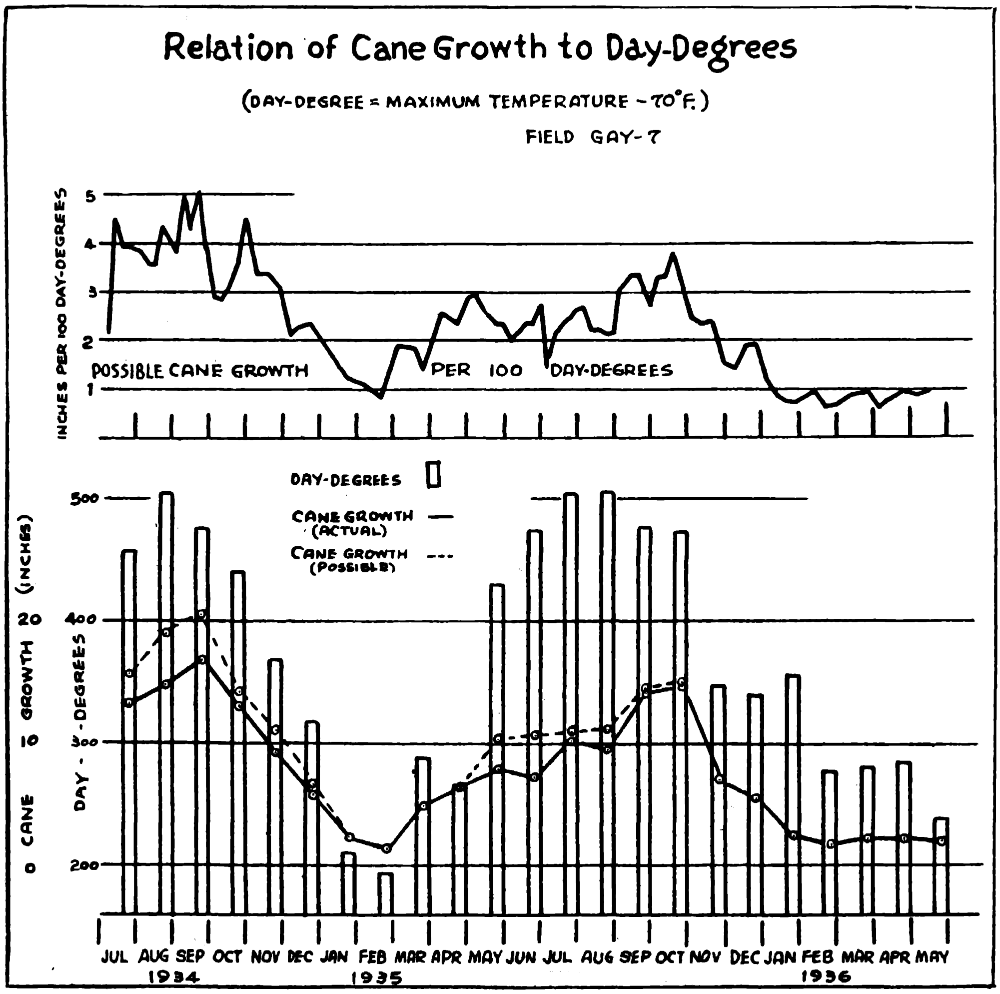


Fig. 21. Gross relationship between growth and day-degrees shown by monthly accumulations. No numerical evaluation of growth-day-degrees relationship is found to hold consistently throughout the crop.

(Fig. 20). The gross relationship is further evidenced by Fig. 21, in which the bar-graph of monthly day-degrees and the superimposed monthly growth show that throughout the crop there is greater growth during warm months than during cold months.

Difficulty in Finding Linear Relationship for Short Periods: Examination of Fig. 20 shows that, although there is a definite gross relation between growth and day-degrees, the relationship is far from precise. There is considerable variation in rate of growth made for any number of day-degrees observed. In Fig. 21 this lack of precision is shown by the curve of growth per 100 day-degrees, which fluctuates not only from season to season, but also fluctuates widely from one short period to another within a season.

TABLE VI

COEFFICIENTS OF CORRELATION

BETWEEN GROWTH PER STALK PER DAY AND DAY-DEGREES

Field	No. of Observations	Coefficient of Correlation
Waimea 3	45	0.455 ± 0.080
Kawailoa 3	50	0.887 ± 0.020
Gay 7	46	0.933 ± 0.013
Mill 2	51	0.686 ± 0.050
Helemano 2-A	45	0.754 ± 0.043
Opaeula 13	53	0.818 ± 0.031
All Stations	290	0.665 ± 0.022

The data do not offer a definitely consistent, quantitative relationship between growth and day-degrees which could be used for crop estimation.

Apparently No Consistent Relationship Between Irrigation Interval and Day-Degrees: Fig. 22 shows for a number of rounds the proper irrigation interval in terms of day-degrees accumulated from date of irrigation. Rounds were selected during which there was no rainfall to complicate the analysis. On each round, starting from date of irrigation, accumulated cane growth is plotted against accumulated day-degrees. The arrows indicate points at which irrigation water should be applied due to exhaustion of soil moisture. These points were determined in the field by the soil moisture observations, and checked by the growth observations.

These curves show that:

1. The relation of cane growth to day-degrees varies from period to period throughout the crop.

2. There is apparently no consistent number of day-degrees accumulated between irrigation and point of soil moisture exhaustion.

The variations in slopes of the curves on Fig. 22 are the fluctuations of the growth per 100 day-degrees shown on Fig. 21. The data indicate that it would be difficult to rely on day-degrees as an aid in determining proper irrigation interval at Waialua.

It can be concluded that, from the data obtained in field tests at Waialua, the day-degree is useful as a qualitative measure in comparing one crop against another. It is difficult, however, to establish a precise linear relationship between cane growth and day-degrees useful for short periods within the crop.

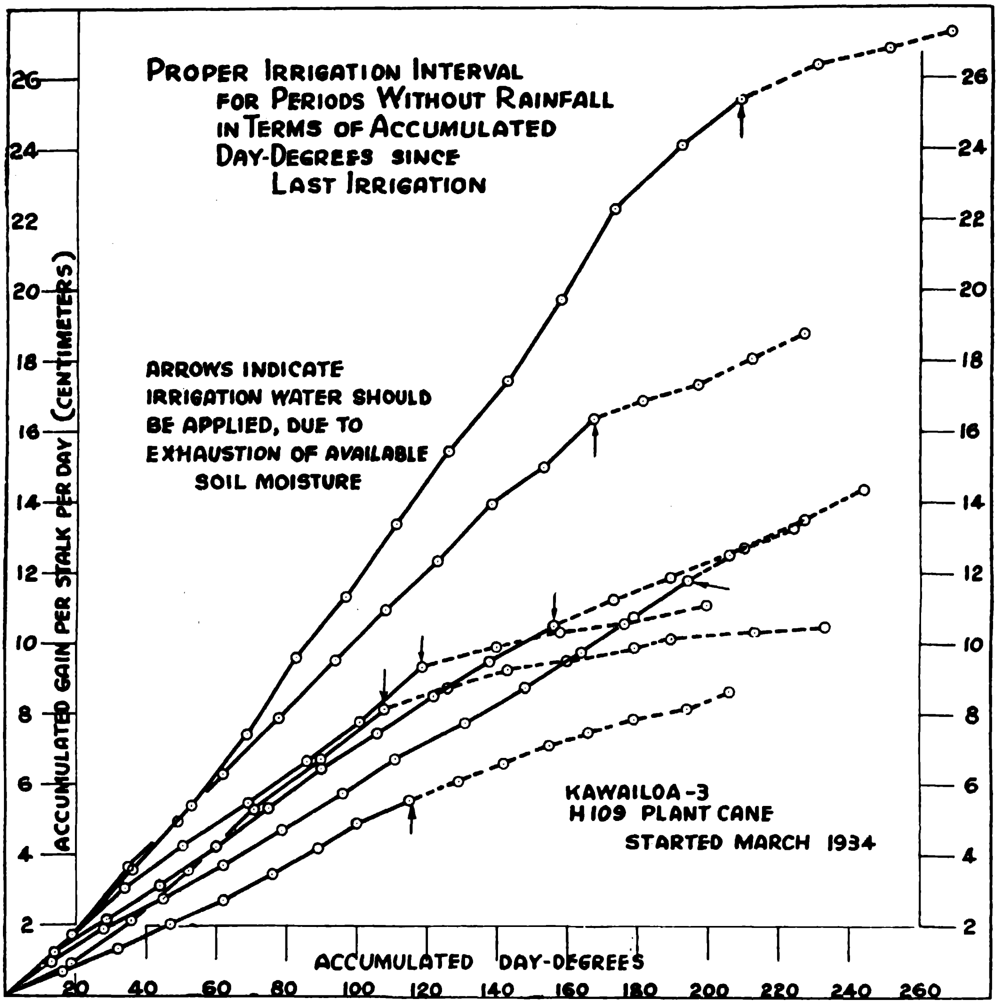


Fig. 22. No consistent numerical relationship is found to hold between proper irrigation interval and day-degrees.

Determinations at Harvest:

Measurement of Twenty Stalks at Each Observation Station: At the time of harvesting each field in which an observation station was located, the following measurements were made and recorded for each of the 20 stalks which were under observation:

1. Total length of stalk, from butt end to highest visible ligule.
2. Millable length of stalk, from butt end to lowest adhering greenleaf.
3. Length of stalk to topping point, taken as closely as possible at the same point as the actual topping being done by the regular cutters in the field.
4. The weight of the topped stalk.
5. A diameter of the stalk taken, at a purely random point on stalk.

Measurement of All Stalks in Four Random Lines: Immediately after removal and measurements of the observation stalks were completed, the remainder of the stalks in the station line were carefully removed and measured in the same way as the observation stalks. After the area surrounding the station was burned, and

before the cutting gang had reached the immediate vicinity, all stalks were removed from each of four random lines surrounding or near the station line. These stalks were measured in the same manner as the stalks from the station line.

Linear Weight of Stalk: It was desired to ascertain the linear weight (weight per foot length) of stalk, as grown under Waialua conditions. Summarizing the data taken at the harvests of the observation stations and referring to the groups of 200 to 400 stalks in the vicinity of each station, it was found that the average linear weight of stalk (in pounds per foot of length) varied from 0.48 to 0.69. It is to be remembered that the fields were harvested at various times between March 1 and September 1, and in different parts of the plantation. The linear weights at the stations were fairly well representative of the fields, but an even more extensive study of weight per foot was conducted in these same fields.

As soon as cane began to reach the mill from each field in which observation stations were located, random sticks were taken from the cars standing in the mill yard. These random sticks were obtained at the rate of one or two per car and 100 per day until the field was finished. In this way stalks were obtained from all parts of the field, the total number per field varying between 498 and 613, with a total from 6 fields of 3,446 sticks.

Each random stick from the cars was measured for length, a single purely random diameter, and weight. These data were averaged by fields, and the data summarized in Table VII.

TABLE VII

SUMMARY OF LINEAR WEIGHT OF STALK AGAINST AVERAGE RANDOM DIAMETER

Field	No. of Random Sticks	Average Diameter in cm.	Weight in Pounds per Foot
Waimea 3	594	3.29	0.584
Kawailoa 3	604	3.51	0.664
Gay 7	521	3.34	0.559
Mill 2	616	3.42	0.551
Helemano 2-A	498	3.27	0.593
Opaeula 13	613	3.30	0.476
All fields	3446	3.36	0.578

The table above by no means presents the entire information available from this study. Taking the 3,000-odd sticks individually, there was great variation in weight per foot: from 0.20 to 0.30 up to something over 1.00 pound per foot. While measuring these sticks the observers noticed what would be obvious to anyone making such measurements: that the heavier sticks were of greater girth, although lengths might be shorter than for some of the lighter sticks. With the complete sets of data at hand, and this observation in mind, the linear weights were analyzed with regard to this apparent relation to diameter. The analysis was made for each field, and also for the entire 3,446 sticks:

The linear weight in pounds per foot was computed for each individual stick. All linear weights were then classified by diameters. The classified linear weights were then plotted against corresponding random diameters. This graph indicated existence of a useful straight-line relationship. The straight lines which most nearly satisfied all pairs of diameters and classified linear weights were computed

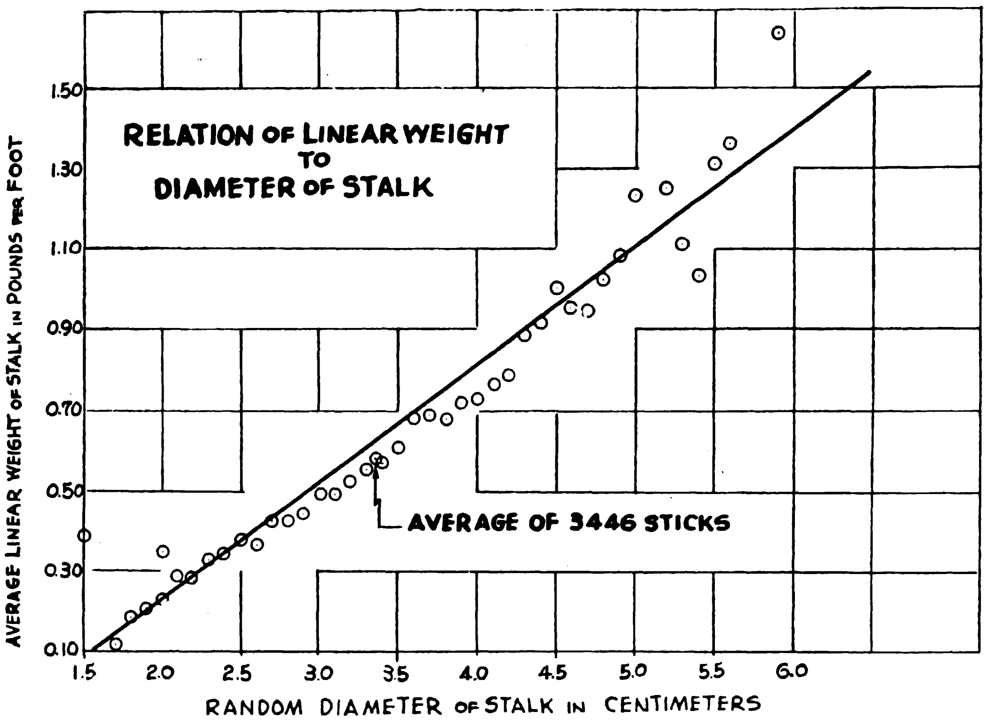


Fig. 23. Observations of random diameter of stalks in a field can be converted by this curve to give weight of stalk in pounds per foot of length.

for each field and for the entire set of data. Fig. 23 shows the graph for 3,446 sticks.

Suggested Methods of Crop Estimation: An estimate of cane yield can be made by the following formula: The yield in tons cane per acre = number of stalks per acre × average length of stalk × linear weight of stalk ÷ 2000.

Since the linear weight of stalk appears to be influenced by the girth, and since it is far simpler, prior to harvest, to obtain actual observations of random diameters than of linear weight, the observations of diameter when referred to the linear weight vs. diameter curve readily give a value, characteristic of the individual field for the linear weight factor in the yield formula. The number of stalks per acre can be obtained by stalk counts in random lines.

Another method of determining the relation between stalk length and yield of cane is to obtain the ratio of the length of representative stalks in the field to the resulting yield of cane, expressed as tons per acre of cane or sugar per unit length of stalk. The method presupposes a relatively constant relationship between length and weight of each stalk, and a relatively constant stalk population in all fields at harvest. The data must be obtained from many representative areas over a period of several crops before they can be employed safely in crop estimation. The method has been used with success on a number of Hawaiian plantations, notably the Honokaa Sugar Company and the Ewa Plantation Company.

The ratio between average length of 20 measured stalks at the observation stations and the yield of cane per acre in the six fields, 1936 crop at Waialua, is seen in Table VIII.

TABLE VIII
RELATION OF LENGTH OF OBSERVED STALKS TO FIELD YIELD

Field	Average Length of 20 stalks	Field Yield Tons cane per acre	Ratio, Tons of cane per inch of measured stalk
Waimea 3	194.43 inches	88.23	0.45
Kawailoa 3	219.07	105.35	0.48
Gay 7	199.72	89.29	0.42
Mill 2	179.05	101.40	0.56
Helemano 2-A	162.68	79.31	0.49
Opaeula 13	204.06	88.39	0.43

Effect of Inadequate Soil Moisture on Cane Tonnage: From this rather consistent relationship between length of stalk and final cane yield, a crop production chart for each field under measurement was made. Fig. 24 is an example. This chart shows the tons of cane per acre produced each week of the crop, and the number of days each week in which the soil moisture content was above the wilting

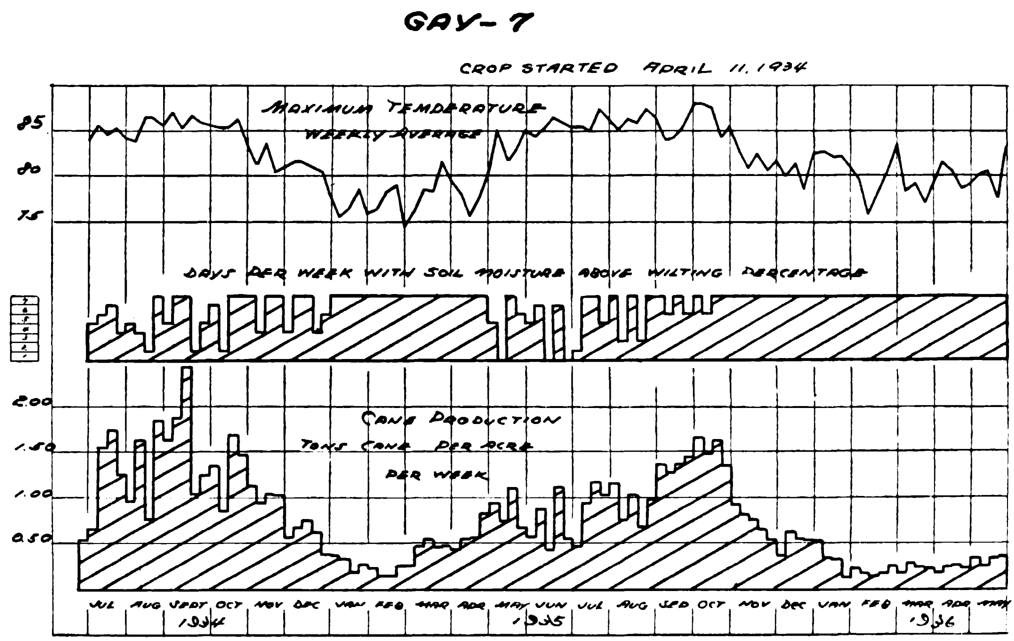


Fig. 24. Amount of cane produced is affected by number of "idle days" during which soil moisture was inadequate.

percentage. The marked effect of inadequate soil moisture in depressing the yield of cane is clearly shown. The total number of "idle days," or periods of soil moisture inadequate to promote maximum cane growth, and the potential cane tonnage lost because of inadequate soil moisture are shown in Table IX.

TABLE IX
PROBABLE LOSSES OF CANE DUE TO INADEQUATE SOIL MOISTURE

Field	Number of "Idle Days"	Probable loss because of Inadequate Soil Moisture: Inches of Stalk	Tons Cane per Acre
Waimea 3	53	9.5	4.28
Kawailoa 3	94	18.2	8.74
Gay 7	112	24.8	10.42
Mill 2	34	7.2	4.03
Helemano 2-A	36	3.7	1.81
Opaeula 13	47	5.5	2.36

This is an amplification of the information already described in Fig. 19, and indicates pointedly the economic importance of the potential cane lost. A program of soil moisture observations should be of great assistance in reducing the number of "idle days," resulting in reduction of these losses and in increased cane yields.

In Fig. 24, notice the pronounced tapering-down of cane growth. Although this would normally be expected during the "drying-off period," it is of note that the soil moisture was maintained above wilting percentage by rainfall throughout this period. There were few, if any, "idle days" due to inadequate soil moisture. Possibly the cane had consumed from the soil very nearly all of the plant nutrients before "drying-off" was commenced.

THE ADMINISTRATION OF PLANTATION IRRIGATION WATER

By H. R. Shaw

Application of Scientific Tools to Commercial Irrigation

We have discussed at some length the methods by which soil moisture and cane growth determinations may be obtained in the field, the results of preliminary studies on fundamental characteristics of growth and moisture relationships on Hawaiian plantation soils, and especially the application of these studies to commercial areas of the Waialua Agricultural Company.

It must not be thought, however, that such measurements in themselves can be a complete and satisfactory answer to the problems of water distribution and application on the plantation. Nothing can, nor should, replace careful observation and supervision in the field. The intelligent management of individual fields by division overseers and their subordinates remains the basic factor of irrigation administration.

Value of Scientific Information to Field Overseer

The plantation management owes certain considerations to its field superintendents and overseers if maximum irrigation efficiency is to be obtained. The division overseer is entitled to a proportionate share of the plantation water supply on the basis of the area he is expected to irrigate, he is entitled to the careful construction and installation of supply ditches and irrigation methods which will assure adequate distribution of water to and within the field, and he is entitled to all the information available on the water requirements and characteristics of the soils and crops with which he is working. It is in supplying and coordinating this information over the entire plantation that the scientific tools of water measurement, soil moisture analyses, and cane growth measurements may be used to obtain higher irrigation efficiency and lower production costs.

Fundamental Considerations in an Irrigation Control Plan

This paper describes the methods of irrigation administration and control now in use on the plantation of the Waialua Agricultural Company. The methods are a slow but logical development over a period of four years, and are subject to considerable further improvement and refinement. The plan of irrigation control is based on several fundamental considerations:

1. *Practicability:* The worth of each operation in irrigation control must be weighed by its value in dollars and cents to plantation field irrigation.

2. *Simplicity:* The division overseer is not a field clerk. Reports from the field must be brief and simple, and should be in a form readily understood and submitted by the irrigator or ditchman.

3. *Applicability:* Irrigation reports are not contributions to ancient history. Data must be capable of immediate application to field operations, of anticipating difficulties, and of correcting errors before they have accumulated.

4. *Flexibility:* Irrigation deals with variable factors of weather, cropping plans, labor and water supply. Irrigation control must be designed to accommodate itself without lost motion to changes in conditions.

Irrigation control and administration at Waialua may be divided into three separate but correlated phases: (a) water measurement, (b) use of water, labor, and cropping data, and (c) use of investigational data.

Water Measurement at Waialua

Types of Measurement:

The rectangular weir, the rated section, and the submerged orifice have long been considered by irrigation engineers as the standards of water measurement in the field. There are, however, many disadvantages to these types of measurement which limit their utility in actual practice. The use of the rectangular weir entails a considerable loss in head, the elimination of velocity of approach, and the frequent removal of silt deposits in the approach basin. The rated section, in which water discharge is determined by measuring the rate of flow over a known cross-section is designed primarily for the measurement of large streams and rivers. The submerged orifice is affected by velocity and direction of approach, by silting and blocking of the orifice, and has a limited flow accommodation. The Venturi meter, in which discharge and rate of flow are based on the pressure differential on either side of a constricted section of closed pipe, is used chiefly for the measurement of pump discharge. When properly installed and maintained, this device is probably the most accurate means of water measurement available; however, its relatively high cost limits its utility to large pumps and pipe lines where in necessity, precision of water measurement outweighs its original cost.

The Parshall measuring flume, formerly called the Improved Venturi flume, was developed by Ralph L. Parshall, Senior Irrigation Engineer of the U. S. Department of Agriculture, in the Hydraulic Laboratory at Fort Collins, Colorado. The first installation locally was made on the plantation of the Hawaiian Commercial and Sugar Company in 1927, and its use and popularity have since spread throughout the Hawaiian Islands. The Parshall flume is arbitrary in design, and specifications

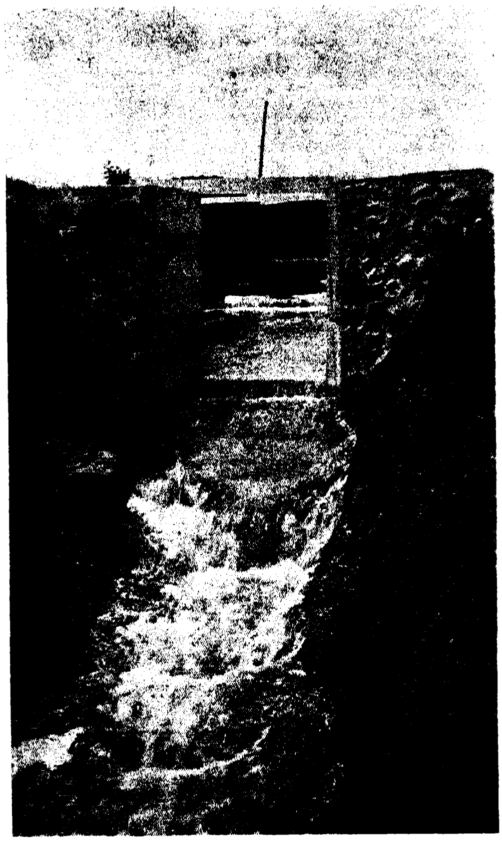


Fig. 25. Parshall flume installation with additional wall height, for measurement of freshet peaks in mountain water ditches.

must be followed implicitly; but from exhaustive tests both on the Mainland and in Hawaii this device appears to be the most practical and accurate means of measuring water in open channels. The Parshall flume is as accurate as the weir, requires but little loss in head, is little affected by velocity or direction of approach, is self-cleaning, and accommodates large fluctuations of flow. The Parshall flume is the standard type of water measurement in use at Waialua; methods of installation and use are described later in this report.

All of the types of measurement mentioned above require a graphical recording device in order to secure proper records of water discharge. Such a record, in addition to registering the head of water passing each control point, gives a complete history of flow, registers flow peaks and night water, and is valuable in planning water distribution and in settling disputes. Several types of graphic registers are manufactured, and are available through local agents. The methods of reading and the use of recording charts at Waialua are described later in this report.

Installation of the Parshall Measuring Flume:—

Technical details of the development, specifications, and installation of the Parshall measuring flume are contained in Bulletin 336 of the Colorado Agricultural College Experiment Station by Ralph L. Parshall.

Early installations of the Parshall flume in Hawaii were made of redwood. As the usefulness of the device became apparent, a more permanent structure was desired. Several individual plantations as well as the Experiment Station, H.S.P.A., developed steel forms from which concrete structures could be cast in place. Usually the floor is cast at the proper elevation, the steel forms set at the desired throat width, and the sidewalls to the required height cast in place. As the angles of the sidewalls do not change with increasing throat widths, a set of cross-members to give

Fig. 26. Parshall flume with concrete floor and redwood sides, for mountain locations.

throat widths of various sizes permits the construction of measuring devices which will accommodate any range of flow found under ordinary plantation conditions.

A modification which increases the utility of the Parshall flume in measuring great fluctuations of flow, such as are found in mountain ditches with a normal low flow but with occasional freshet peaks, is the use of a relatively narrow throat with sidewalls higher than the standard 2.5 feet. Thus the head of water under normal low flows is great enough for accurate measurement, while freshet flows can be accommodated without flooding the structure and can be measured with sufficient precision. In a personal letter to the writer, Mr. Parshall comments on this modification of the Parshall flume as follows: "I see no theoretical or practical reason why you cannot use the flume for heads of more than 2.5 feet. My suggestion would be to increase the length of the converging section. This will smooth out the stream

Fig. 27. Parshall flume installation—casting sidewalls 4.5 feet high in place.

lines and give a very good hydraulic condition. It is important, however, to maintain the 'H_a' gage point at the standard distance back from the crest."

The use of a concrete floor with redwood sides for the construction of the Parshall flume in localities accessible only by pack mules or by hand carrying was first employed by the Pioneer Mill Company. This method obviates transportation of the bulky steel side forms, and permits accurate water measurement under conditions which could be met otherwise only by the use of the rated section and current meter. At Waialua, where two such structures have been installed, the sidewalls and timbers are cut to size in the plantation shops, and are packed to the site by mules or by hand from the end of the truck road. The construction of the concrete floor and the erection of the sidewalls can be made rapidly and accurately by a few men.

The construction of concrete Parshall flumes cast in place has several disadvantages. The steel forms are heavy, cumbersome, and often get out of alignment after a few years' use. The short time usually available for construction frequently prevents the concrete from curing properly before water is turned into the ditch. From three to four days is generally required for casting a Parshall flume.

To avoid these disadvantages, Waialua Agricultural Company has developed precast concrete slabs, poured to precise specifications, for field installations of the Parshall flume with two-foot throat. Thirteen slabs, having a total weight of 2,511 pounds, are fitted by dovetail joints to form each flume unit. The cost per unit at the plant is $7.03, with six man-days required for erection in the field. A precast Parshall flume may be erected and ready for use in two days.

Each measuring device installed at Waialua is equipped with a 24″ x 24″ stilling well, a meter house with hook gage, and a staff gage graduated in units of flow rather than head for the use of ditchmen and overseers. A graphic water-level recorder is not necessarily installed at each flume but may be moved from one station to another as the need for continuously recorded flow and discharge arises. The meter house is of simple, rainproof construction with ample room for maintenance of the meter. The hook gage is a ¾″ x ¾″ wooden rod with an inverted brass hook at the

lower end. The difference in elevation between the floor of the Parshall flume and a convenient point on the platform of the meter house is obtaind by an engineer's level. With the extension of the point of the hook to the rod as zero, the difference in elevation is marked in hundredths of a foot on the rod. The hook-gage rod is placed vertically through a square hole in the house platform with the brass hook in the water of the stilling well. The rod is adjusted so that the point of the hook just pierces the surface of the water, and the head of water is read directly from the

Fig. 28. Setting crest and floor, precast Parshall flume.

rod at the platform datum. The staff gage is graduated in units of million gallons per 24 hours and, in many cases, in units of acre-inches per hour so that no discharge tables are required by the ditchman or overseer to determine the flow of water through any station on his division. Two types of staff gage are in use at Waialua. One developed by Engineer C. A. Brown of Pioneer Mill Company employs a rigid wire rod attached to a small float in the stilling well and leading to the staff gage on the meter house platform. As the water level rises or falls, the indicator on the upper end of the rod points to the rate of flow. The other type is a stencil in units of million gallons per 24 hours which is painted at the proper point on the wall of the approach section in the flume, and is renewed when necessary.

Classes of Water-Measuring Stations:

Three classes of water-measuring stations are in use at Waialua. The Distribution System has 28 stations, chiefly two-foot and four-foot Parshall flumes, situated at strategic locations to measure all gravity water received on the plantation and to measure water passing on each supply canal from one division to another. Each station is equipped with a weekly graphic recorder and flow staff gage, and is checked

Fig. 29. Erecting sidewalls, precast Parshall flume.

many times a day by ditchmen and overseers to insure proper delivery of water. The Pump Discharge stations, generally two-foot Parshall flumes, are installed at the outlets of pumps not equipped with Venturi meters. They may or may not be equipped with recorders, and are used chiefly to check rates of flow and to determine whether or not a pump is delivering its rated capacity. Field measurement stations, chiefly precast two-foot Parshall flumes, are installed at the head of representative fields of different soil types and under different methods of irrigation to determine net water requirements of plantation areas and to check the efficiency of field irrigation. Most of these stations are equipped with recorders, although the meters may be moved from site to site as the need arises. Other stations are installed to fill specific tasks such as checking the distribution of water through important reservoirs and straight ditches, measuring seepage losses, and determining the size and constancy of potential sources of water supply.

Reading Meter Charts:

The chart from most water-level recorders is a continuous graph of height of water passing through a measuring station against units of time. In no type of measuring device is the discharge of water directly proportional to the head. Therefore, it is never correct to compute water discharge by obtaining the average head over a given period of time and noting the discharge equivalent to the average, nor is it correct to trace the graphic record of water heights with a planimeter and

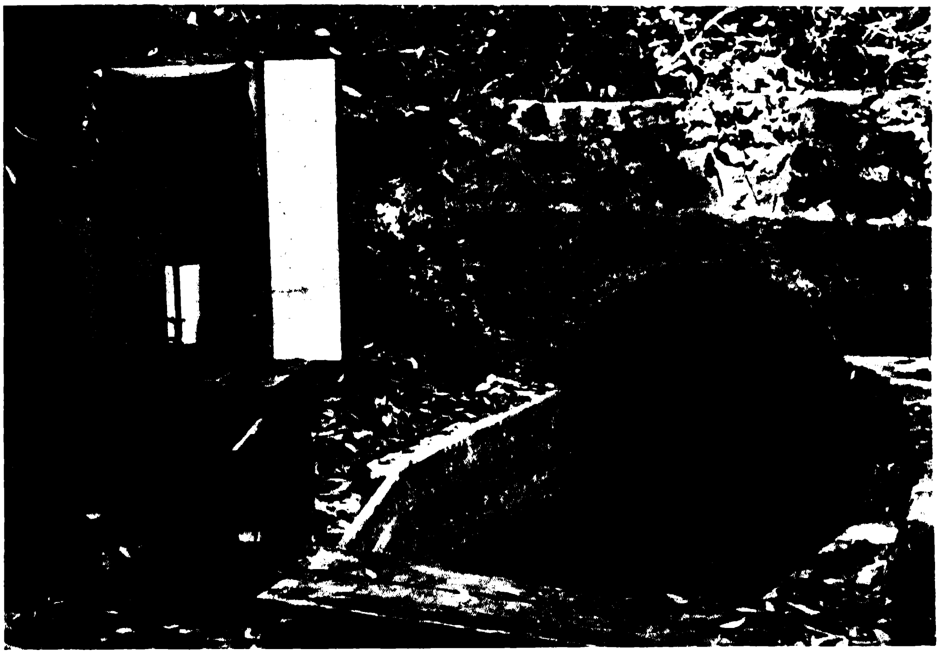


Fig. 30. Parshall flume with recording meter, staff gage and hook gage for use in irrigation control.

compute discharge from the entire area under the curve. The true discharge of water for any period of time must be determined from the sum of discharges equivalent to each change in water height.

A rather simple, accurate, and rapid means of determining and recording water discharge is used at Waialua. The recorders are equipped with pencils so that the records may be erased and used again. It is desirable, however, to have a permanent record of flow in each ditch not only for checking results but in order to re-create the flow curve if necessary. In reading the charts we use a "discharge overlay," which is a two-inch strip of meter-chart paper with the equivalent discharge of water for the measuring device and gage-height ratio in use indicated for each increment of height. The "flow sheet" is a mimeographed form with spaces for identification of the measuring station and for entries of the rate and duration of each stage of flow throughout the week. The discharge overlay is placed on the meter chart with zero lines coinciding and is moved along the chart in that position until the pencil record of water heights intersects the equivalent discharge on the overlay. Discharge is expressed in "acre-inches per hour," which is essentially equal to the unit, "cubic feet per second," in which most discharge tables for the weir and Parshall

flumes are written. The discharge equivalent to the intersected gage-height record of the meter chart is entered in the first column of the flow sheet. and the number of hours through which this rate of flow continued is entered in the second column. In like manner the discharge overlay is moved along the meter chart, with rate and duration of flow entered on the flow sheet for each change in the height of water indicated by the pencil line. The duration of flow is usually taken in units of even hours although interpolated decimals of an hour may be used if significant changes in water height occur within the hour. The "water day" is considered as the 24 hours from 5:00 p. m. to 5:00 p. m., as delivery for each day's irrigation usually takes place within that time. When the week's record has been read and entered on the flow sheet, the rate of flow in acre-inches per hour is multiplied by the duration of

KEMOO DIVISION

W.A.CO., LTD.

MONTHLY SCHEDULE OF IRRIGATION INTERVALS

Based on 31 calendar days and 27 working days.

MONTH OF OCTOBER 1936

Crop	Field No.	Area	Age in Months	PROPOSED INTERVAL (DAYS)			Acres per Day	Acre-Mos. Sched.
				FIELDS UNDER PUMP WATER				
1938	Valley 1B	20.31	2.1	12			1.88	50.78
1937	" 1A	88.80	14.2	18			5.49	148.30
1938	" 2	26.01	4.6	12			2.41	65.03
Pali 1937	" 2AB	20.51	13.6	12			1.90	51.28
Flat 1937	" 2AB	60.13	13.6	18			3.72	100.42
1938	Old Mill	34.58	2.0	12			3.20	86.45
1937	Kemoo 1	30.47	14.5	15			2.26	60.94
1937	Kemoo 1B	107.74	15.2	15			7.98	215.48
1937	Kemoo 3	30.31	14.3	15			2.25	60.62
				FIELDS UNDER MOUNTAIN WATER				
1937	Kemoo 1A	33.52	17.3	15			2.48	67.04
1938	" 2A	50.16	4.0	10			5.57	150.48
1937	" 2B	60.21	16.5	~~15~~	12		5.58	150.53
1937	" 3	27.81	14.3	15			2.06	55.62
1938	" 4	88.94	4.5	12			8.24	222.35
1938	" 5	30.10	4.2	12			2.79	75.25
1938	" 6	76.05	4.5	12			7.04	190.13
1938	" 7	52.67	5.0	12			4.88	131.68
1937	" 8	37.78	13.3	15			2.80	75.56
1937	" 9	71.34	15.3	25	} Ripening	as of 10/15	~~3.17~~	~~85.67~~
1937	" 10	15.97	15.2	25	}		~~0.71~~	~~19.16~~

Total Acres under Irrigation 963.41 — 87.31 (10-15-36)

Total Acres Ripening 87.31 (10-15-36)

Total Acre-Months Scheduled 2062.71 - 104.77 (10-15-36)

APPROVED

W. C. Irwin

Division Overseer

W. L. Pritchard

Head Overseer

H. R. Shaw

Irrigation Overseer

Fig. 32. From area to be irrigated and daily acreage to be covered, labor and water required are readily obtained. This schedule is extremely flexible.

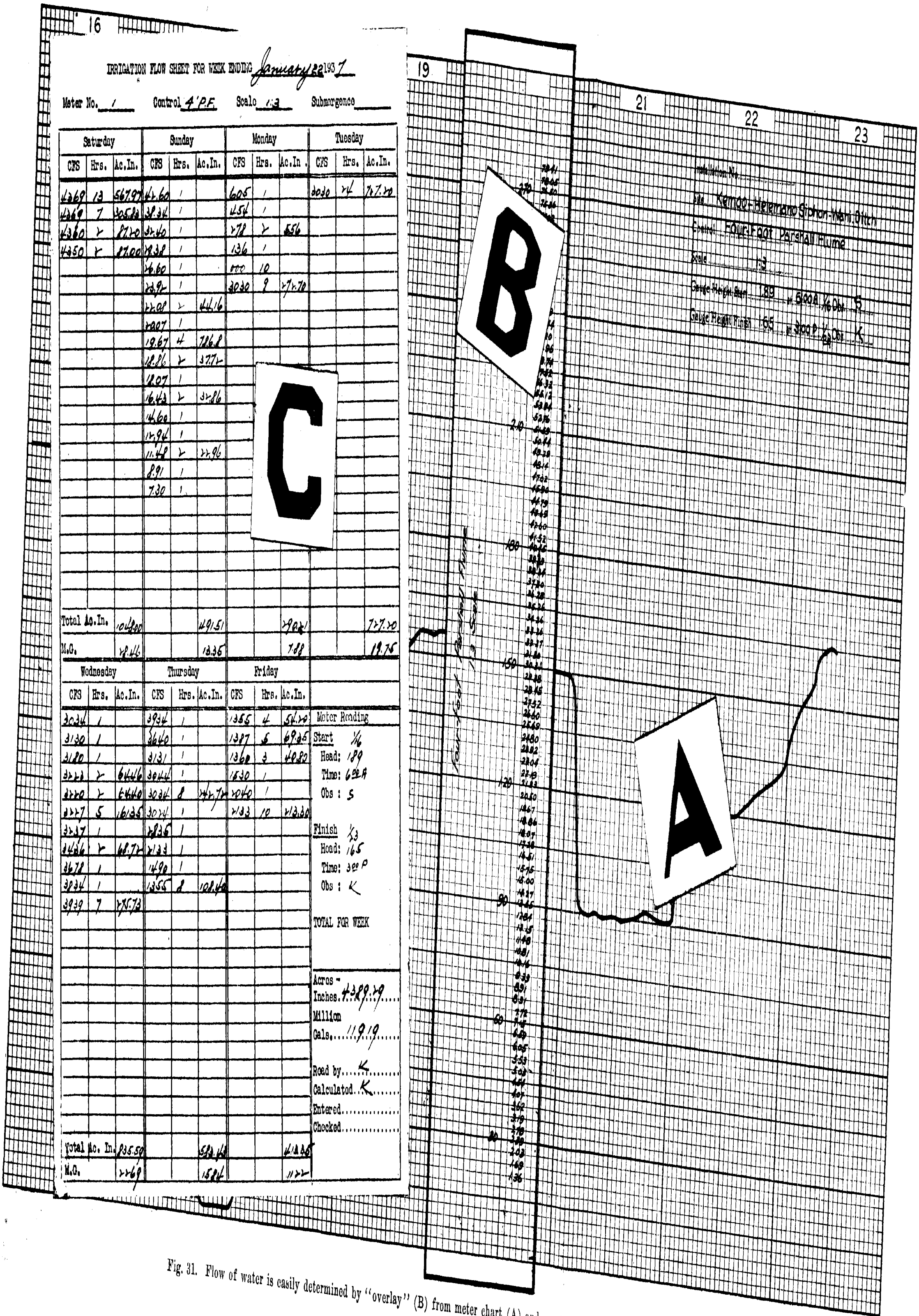


Fig. 31. Flow of water is easily determined by "overlay" (B) from meter chart (A), and permanently recorded on flow sheet (C).

flow in hours and the total acre-inches delivered for each day entered at the foot of the column. Acre-inches may be converted to million gallons by multiplying by the factor 0.027.

With such a system a clerk can compute rapidly and accurately the discharge of a large number of measuring stations. The results are summarized in a "water balance" in which the daily discharge of water received and delivered on every main supply canal is posted for each plantation division. Information for the weekly reports on relation of water consumption to area irrigated and labor used, as described later in this report, is drawn largely from the Water Balance Summary.

Use of Water, Labor, and Cropping Data

Monthly Irrigation Schedule:

The chief basis of water distribution at Waialua is the "monthly irrigation schedule" (Fig. 32). The schedule lists the number, area, crop year, and age at the first of the month for each field of every division. The interval between irrigation desired for each field, or portion of the field, for the coming month is determined by the soil type, season, age of cane, and the water supply available for each area. Current investigational data on the rate of soil moisture depletion and rate of cane growth are used fully in assigning the desired interval. After the irrigation schedule is made out by the irrigation overseer, it is discussed with the division overseers, the head overseer, and the manager. Modifications or changes are noted. The total area to be irrigated during the month and the area to be irrigated daily in each field to maintain the desired interval are then calculated. The area to be irrigated daily is the key figure in planning water distribution and in checking irrigation progress. Each division overseer and water luna is informed of the area to be covered daily in each field, and of the water he will receive and deliver in each supply area to meet the desired irrigation interval. He distributes water and labor to the fields within the supply area so as to cover the daily area requirement. The irrigation schedule is very flexible, and may be changed several times during the month. As water supply increases or diminishes, as fields are added or taken out of the area to be irrigated, or as observation and investigational data indicate the desirability of increasing or decreasing the interval between irrigations, the area to be irrigated daily in each supply area is changed accordingly.

Water Distribution Tables:

A basic table of water to be received and delivered on each supply canal is prepared from the monthly schedule, and division overseers are held responsible for the proper distribution of water to the next division. The water distribution is checked frequently through the use of the measuring stations.

Field Reports:

Field reports on daily irrigation accomplished are in the simplest form possible, and are made out and submitted by the field irrigator or water luna. The ditch number and area under each level ditch, ranging from two to five acres in size, are listed in the irrigation office. The corresponding ditch number is indicated on a

stake at the entrance to each level ditch. The field ditchman reports the numbers of the ditches his men have completed, and the number of men irrigating in the field. A circle is placed around the number of ditches partially irrigated but not completed, and the ditch number reported again the following day when irrigation is completed. The reports are received early the following morning by a clerk in the irrigation office, who summarizes the daily irrigation in a time book, showing the ditch numbers completed and the men irrigating daily in each field on the plantation. The area irrigated and the labor required is totalled weekly, or at more frequent intervals if desirable.

The status of irrigation is shown in an "interval report," issued daily during the irrigation season. Our interest centers in assuring that each ditch, or similar small area within the field, is irrigated at the scheduled interval and that the information is available promptly so that errors can be corrected immediately. The interval report, issued to the head overseer, the irrigation overseer, and the division overseer concerned, shows the ditches within each field of every division which on the previous day were irrigated more than one day ahead or more than one day behind schedule. The report on each day's irrigation is available by noon of the day following the irrigation. The interval report has proved highly useful in adjusting water distribution within the division, releasing labor from irrigation for other operations, and in assuring prompt and effective action in correcting errors. The human tendency to make the field reports what the bosses would like rather than what was actually accomplished has proved discouraging to the ditchmen making the basic field report, as they found themselves in such a maze of complications that "doctored" reports soon disappeared. Of their own volition, most of the division overseers and water lunas have adopted the practice of entering in their time books the number of the ditches irrigated daily for each field in order to anticipate and prevent any of their areas appearing in the interval report.

TYPICAL REPORT USED AT WAIALUA TO CHECK IRRIGATION PERFORMANCE

Division: Kemoo Date: October 10, 1936

DAILY IRRIGATION INTERVAL REPORT

Fields Behind Schedule				Fields Ahead of Schedule			
Field	Interval Scheduled	Days	Ditches	Field	Interval Scheduled	Days	Ditches
Kemoo 2A ...	10	2	6, 7	Kemoo 2B ...	12	3	1, 2
Kemoo 5	12	4	3	Kemoo 8	15	2	10
Kemoo 7	12	1	2, 6				

Weekly Irrigation Reports:

A "weekly irrigation report" (Fig. 33) summarizes the progress of irrigation throughout the year. From the water balance are drawn data on the total amount of water received and delivered, and from the summarized field reports are shown the area irrigated and labor required on each division of the plantation. The resulting data on application of water and on performance of labor provide a guide to relative irrigation efficiency, give an experience basis on area irrigated per million gallons of water for use in water distribution, and are essential in planning cropping schedules, water requirements, and future developments.

WEEKLY IRRIGATION REPORT
WAIALUA AGRICULTURAL COMPANY, LIMITED
WATER AND LABOR DISTRIBUTION FOR WEEK ENDING 5:00 P.M., Friday October 2, 1936

	Kaw'pai	Mok.	Ranch	Kamoo	Hale.	Opae.	Kawailoa	Waimea	Plantation
Million Gals. of Water:									
Received	32.40	86.93	231.41	282.54	381.11	339.06	256.74	84.55	995.02
Delivered	1.00	5.96	73.76	194.45	197.09	172.50	91.28	3.00	39.32
Consumed	31.40	80.97	157.65	88.09	184.02	166.56	165.46	81.55	955.70
Average Applications:									
Acre-Inches Per Acre	4.76	5.80	7.25	5.92	6.64	7.80	8.56	6.37	6.91
Acres Per Mil. Gals.	7.73	6.38	5.08	6.22	5.55	4.72	4.30	5.78	5.33
Average Per Man:									
Acres Per Day	3.92	3.19	3.10	2.98	3.24	2.35	3.49	2.78	3.02
Million Gallons	0.507	0.503	0.611	0.479	0.584	0.499	0.811	0.480	0.566
Area Irrigated in % Total Under Irrigation	59.94	59.60	59.69	57.04	57.01	52.41	56.75	52.43	56.53
Average Interval (Days)	11.7	11.8	11.7	12.3	12.3	13.4	12.3	13.4	12.4
Average Crop Age	7.9	7.7	9.5	10.6	8.9	7.0	8.9	6.9	8.6
Acres Under Irrigation	404.95	863.10	1341.65	960.51	1790.29	1499.67	1254.14	899.75	9014.06
Acres Ripening or Fallow	88.70	----	67.74	----	87.49	164.96	----	----	408.89
% Total Under Irrigation	82.03	100.00	95.19	100.00	95.34	90.09	100.00	100.00	95.66
Acres Irrigated This Week	242.74	514.36	800.82	547.86	1020.66	786.00	711.66	471.72	5095.82
Number of Men	62	161	258	184	315	334	204	170	1688
Acres Irrigated This Month	71.86	180.50	256.18	178.60	352.60	276.44	210.54	197.42	1724.14
Total Acres Scheduled This Month	892.40	2052.28	3113.98	2218.54	4008.00	3487.36	2883.32	2037.80	20693.68
Per Cent Completed	8.05	8.80	8.23	8.05	8.80	7.93	7.30	9.69	8.33

H. R. Shaw
Irrigation Overseer

Fig. 33. This report assists the division overseers in balancing labor and required water so as to attain higher irrigation efficiency.

The four reports described above form the basis for irrigation administration and control on the Waialua Plantation. The data provide material for other valuable reports on the efficiency of various irrigation methods, comparisons of irrigation performance with that of past years, and on the relation between irrigation performance and crop yields.

Use of Investigational Data

The methods of soil moisture and cane growth analyses described in previous portions of these reports are of value to commercial irrigation only so far as plantation executives, division overseers, and water lunas use the information intelligently. Research and investigational data are considered merely as tools which can be used to obtain better and cheaper production. Such success as we have gained from irrigation investigations at Waialua has resulted from high standards of accuracy, from a rapid and well-organized program of obtaining and analyzing data, and from prompt reports expressed in terms easily understood and applied by field overseers to commercial irrigation.

Use of the Moisture Equivalent Survey:

The classification of all plantation soils on the basis of their water-holding characteristics as measured by the moisture equivalent has proved to be an excellent investment. Considerable pains were taken to make the survey accurate, especially since this was the first time the moisture equivalent procedure has ever been used

for field surveys on so great an area. Some of the practical applications of the moisture equivalent data to field irrigation have been:

1. As a standard of water requirements for plantation fields, the moisture equivalent provides a rational basis for estimating the amount of water required for various soil types. At the present stage of development in irrigation methods, the relative water consumption on different areas appears to be dominated more by the slope of the land, age of cane, and distribution of moisture within the area than it is by differences in the soil's ability to hold water. The net water requirement estimated from the moisture equivalent values, however, provides an index of irrigation efficiency between various cane areas.

UTILIZATION OF GROSS WATER APPLIED, WAIALUA AGRICULTURAL CO., LTD.

	Application in Acre-Inches per Acre per Irrigation				
Division	Net Requirement based on Moisture Equivalent of Soils*	Actual Gross Application, 1934	Per Cent Gross Water Utilized	Actual Gross Application, 1936	Per Cent Gross Water Utilized
1..........	3.09	5.62	55.0	6.03	51.2
2..........	3.17	7.22	43.9	5.63	56.3
3..........	3.31	8.69	38.1	7.94	41.7
4..........	3.17	8.73	36.3	5.91	53.6
5..........	3.05	9.04	33.7	6.65	45.9
6..........	3.11	8.06	38.6	7.49	41.5
7..........	3.02	8.49	35.6	8.22	36.7
8..........	3.15	6.28	50.2	5.62	56.0
Plantation.....	3.13	8.06	38.8	6.90	45.4

* Basis of estimate: Requirement (acre-inches per acre) $= \left(\text{M.E.} \times 1.1 - \frac{\text{M.E.}}{1.2} \right) \times$ Volume Weight $\times$ Desired penetration (inches).

2. As a basis for identifying "dry spots" or areas of low moisture-holding ability, the moisture equivalent survey plotted on field maps points out areas of poor soil which may require differential irrigation treatment, either by scheduling faster intervals between rounds for certain ditches or by varying the amounts of water to certain areas.

3. As a basis for eliminating marginal lands, the moisture equivalent survey is used as one of the bases of judgment in abandoning production areas under quota restrictions. It is also one of the considerations pointing to the belief that by concentrating water and other growth factors on the most responsive land, total production can be increased at lower operation costs.

4. As a basis for interpreting results of soil moisture analyses in the field, the moisture equivalent survey is indispensable. Previous discussion has demonstrated that a relatively small proportion of the total water in the soil after irrigation is actually available for plant growth. Unless an index, such as the moisture equivalent, of the soil's ability to hold and retain water is known, total moisture determinations are valueless.

Use of the Investigations on Plant and Water Relations:

One of the outstanding advantages of the general investigation in relation to commercial irrigation over the formal field experiment, in which results are not available

until the crop is harvested, is that we were able to apply some of the information acquired within six months of the start of the studies. The relationship between cane growth, soil type, and irrigation water was shown so clearly and indisputably by frequent measurements of the progress of the crop that the results could be applied immediately and without question to similar commercial areas. A general increase in plantation irrigation efficiency was reflected in faster applications of water during the summer growth months, more infrequent irrigations during the winter when soil moisture was high, and a better realization by all concerned of the value of water and of the causes and effects in commercial irrigation.

General interest in the results of the field investigations resulted in frequent requests from the plantation management and from division overseers for information on the soil moisture status of areas not included in the original studies. Such information was particularly valuable in deciding the date to resume irrigation after general rains, and in deciding the proper irrigation interval on various areas during hot summer weather. These requests were met by using the moisture equivalent survey as a basis for estimating the limits of soil moisture available for cane growth, and by obtaining total moisture samples from soil areas at or close to the moisture equivalent sampling site. By comparing the "relative wetness," or ratio of the two values, a serviceable guide to the amount of water already used between the date of last irrigation or rainfall and the date of sampling was obtained, as well as the probable number of days before the area would again need irrigation.

Index Stations for General Plantation Control:

A carefully planned program of soil moisture and cane growth measurements over the entire plantation was inaugurated in 1936 as a guide to better irrigation control and performance. In each field harvested during the 1936 crop, one or more stations were established on the basis of the moisture equivalent survey and inspection and consultation in the field with division overseers and water lunas. The number of stations in each field depends upon changes in soil type and field slopes within the area, but averages one station for every 50 acres under irrigation. At each field station, soil moisture determinations and cane growth measurements of 10 marked stalks are taken at weekly intervals. The results are reported to the head overseer, the irrigation overseer, and the division overseer concerned in terms of acre-inches of water still available in the soil, the rate at which moisture has been extracted from the soil during the period between the last irrigation and the current sampling, and the proper interval between irrigations under prevailing conditions if the soil moisture reservoir is to be filled before cane growth is checked because of inadequate soil moisture. The reports are used in supporting or modifying the scheduled irrigation interval on which water distribution is based, in indicating areas which require immediate or special attention, and in determining more precisely the date of starting irrigation after general rainfall. The data on weekly growth rates trace the development of the crop, indicate the relative response of various areas to fertilizer and water applications, and form a sound basis for crop estimates.

TYPICAL REPORT OF SOIL MOISTURE AND CANE GROWTH OBSERVATIONS
SOIL MOISTURE INDICATIONS

Division Ranch Date: Oct. 13, 1936

Field	Sta. No.	Field Capacity Ac.In./Ac.	Available Ac.In./Ac.	Extraction Rate Ac.In./Day	Days after Irrig.	Proper Interval (days)*	Cane Growth (feet) This Week	To Date
R—3	25	3.33	0.73	.29	9	11	.36	4.61
R—2B	27	3.40	1.82	.23	7	15	.25	14.10
R—2B	28	3.66	2.01	.28	6	13	.20	13.87
R—9	30	2.90	0.92	.17	12	17	.15	11.73
R—10A	33	3.33	0.43	.36	8	9	.30	8.52
R—10A	34	3.43	1.09	.20	12	17	.27	7.64
R—1	41	3.14	—0.56 (Subsoil dry)	.45	8	7	.17	2.12

* Days after last irrigation.

Cost of Irrigation Investigations and Control

The irrigation investigations at Waialua are designed to furnish a maximum amount of useful and applicable information with a small, well-organized staff. One clerk maintains the 64 water-measurement stations now in operation on the plantation, changes and reads the meter charts, and makes out all water reports. Another clerk posts all labor and field irrigation data, prepares interval and round reports, maintains the meteorological station and plantation rainfall reports, and is responsible for the preparation and filing of all other reports and memoranda. A laboratory clerk is responsible for the analyses of soil moisture and cane growth determinations, makes the reports on soil moisture indications, and prepares all charts, graphs and other drafting. A crew of three men in a light truck obtains the soil moisture samples and makes the cane growth measurements at about 40 field stations each day, covering the entire 10,000 acres of the plantation weekly.

Results of Irrigation Investigations and Control on the Plantation

The final analysis of the value of any operation lies in its ability to produce results and to reduce costs. Increased irrigation efficiency at Waialua over the past few years has been due to a number of related causes: favorable conditions of water supply and rainfall in 1935 and 1936, greater area planted and better physical condition of the fields, increased area under more efficient methods of irrigation, and a concerted and determined effort on the part of all concerned to obtain maximum results with labor and water. Perhaps the most gratifying result directly attributable to irrigation control has been the complete elimination of disputes over water distribution between divisions, the friendly competition in establishing new records of efficient irrigation, and the interest and concern of water lunas and field irrigators in the "acre-inches" in their areas. The soil moisture investigations have justified themselves in one season by providing a rational basis for shutting down high-cost pumps and reducing irrigation expense in areas of high soil moisture.

The consistent increase of irrigation efficiency at Waialua over the past three years is shown as follows:

ANNUAL IRRIGATION PERFORMANCE, WAIALUA AGRICULTURAL CO., LTD.

	1936	1935	1934
*Total Area Irrigated	155,036	126,773	143 666
Million Gallons Water Delivered	29,067	25,554	31,464
Acre-Inches per Acre per Round	6.90	7.42	8.06
Acres Irrigated per M.G. Water	5.33	4.96	4.57
Number of Man-days Irrigating	54,118	58,649	83,783
Acres Irrigated per Man-day	2.86	2.16	1.71
Per Cent Total Area in New Methods	36.8	22.9	9.5
Tons Cane per Acre	86.37	81.82	75.51
Tons Sugar per Acre	11.29	11.12	10.87

* Number of Acres under Irrigation × Number of Rounds of Irrigation.

The scientific tools of water measurement, soil moisture analyses, and crop measurement are being used successfully and practically on a representative sugar plantation. The application of scientific procedure to commercial irrigation has been a logical development of basic principles demonstrated under carefully controlled conditions, and a close scrutiny of these principles as applied to general field areas. Each step of the development has been made only after careful consideration, and only when the probable results could be seen in the light of direct application to more efficient irrigation and lower production costs.

Success in the use of scientific tools in irrigation is entirely dependent upon mature judgment in the application of the data, complete cooperation of the plantation executives, and a real interest on the part of the plantation field staff. Given such conditions, a similar program of irrigation control and investigation should prove an excellent investment for any plantation on which production costs are largely dependent upon economical field irrigation.

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The Value of Irrigation Water as a Factor in Interval Control

By H. A. Wadsworth

Recent studies upon the general relationships existing between soil moisture and cane growth (3) have developed a practical field technique for determining suitable irrigation intervals when the end in view is to secure maximum yields of cane at minimum costs. It is evident that the proposed procedure finds its most immediate application on plantations enjoying unlimited water resources at a fixed cost per unit volume of water. When such conditions exist it should be possible through the application of established principles, to reduce waste of both water and labor to an economic minimum.

Unfortunately such conditions do not often prevail on sugar plantations in Hawaii. Mountain streams are subjected to great fluctuations in flow. And too often such variations are synchronous with variation of rainfall in the cropped area. Thus full streams and consequently full ditches are available when the need for them is least. Conversely, limited water resources in gravity canals are usually associated with fields at or near the permanent wilting percentage and under such climatic conditions that the time between rounds should be markedly reduced The so-called "Waialua Procedure" is unquestionably of great value under such conditions since it limits losses of water, but alone it provides no measure of the economic value of an irrigation upon fields of varying ages.

The general recognition of this problem is not new. For instance in 1928 Alexander (2) reported the results of three years intensive study at Ewa. Here the relative values of irrigation water applied to young ratoons, young cane, and cane in the "boom stage" were discussed and definite priorities established toward the end of the most economic use of available water resources. More recently Agee (1) has discussed the relative values of irrigation water on fields of different ages under conditions of extreme water shortage. But here emphasis is placed upon increasing amounts of water required per round in older cane rather than upon the sugar-producing ability of the water when applied to cane at different ages.

Cost and Value:

We are all apt to confuse the cost of water with its value or if this is not done, to assume that the value of water increases uniformly over a plantation as scarcity develops without distinction between fields in the different age groups. But it is evident that neither is correct. The cost of water is readily ascertained in any particular situation if all necessary data are available; the value of water is a complex function of many variables. To determine the momentary value of water week by week and field by field is a difficult and perhaps impossible task, but we can strive for an estimate of its value.

Although professional economists may object, it may be suggested that the *value* of irrigation water is measured by its ability to produce wealth or, in our case by

its ability to produce sugar. By this definition mountain water being allowed to waste at spillways or in leaking reservoirs has no value although it does have cost. Water lost into the subsoil by faulty or poorly supervised irrigation methods falls into the same category, but water applied to fields producing sugar at the rate of a ton or more per acre per month may have a value equal to many times its cost. One must be quick to remark that not all the water developed can be expected to bring in any such returns. Fields past the age so aptly called the "boom stage" by Alexander may well be kept growing but here the return of sugar per unit of water is lower, although to a certain point is still on the profit side. Moreover young fields must be kept coming against next year's grinding season. Here the value of the water lies in the protection of the investment made in that planting and not in the worth of immediately recoverable sugar. In the consideration of these values, and the determination of what sacrifices may best be made in time of severe water shortage, are problems that would challenge the skill of Agee's (1) plantation evaluator.

It is probable that immediate objection will be made to the implied statement that the worth of the sugar produced is to be credited to the irrigation water. Fertilizer, cultural practices, pest and disease control all contribute beyond doubt; adequate and timely irrigation would be futile without the high developments that have been secured in these fields. But for the sake of simplifying a complex situation it may be considered that on intensively irrigated plantations irrigation manipulation is the most potent single variable in the hands of the management.

The Problem of Water Evaluation:

Vague as the problems suggested above may be and poorly equipped as we may find ourselves to solve them in terms of dollars and cents, we may find some method of approximation which will at least give relative values. Apparently the plantation cost figures, which supposedly would be available, form the crux of the study. Our irrigation evaluator, to again use the borrowed phrase, would know the cost history of every field with its component items of general overhead, land preparation, cultivation costs and fertilizer as well as the cost of water and the labor used in applying that water. Against this accumulating cost is to be set the hope of sugar yield. From recent work at the Experiment Station we are led to believe that recoverable sugar is to be found in the cane at an age of six months, that the rate of sugar formation reaches a maximum of perhaps one ton per acre per month between the ages of nine months and twelve months after which the rate falls off rather rapidly. It is these rates that our irrigation evaluator must consider. He must balance the rate at which cost is increasing in any field with the rate at which recoverable sugar is being formed. He would suggest harvesting a field, if other things are equal and if irrigation water be abundant, when an additional unit of water does not give promise of value in excess of cost. In case of limited water resource he should be able to give the sugar producing value of water on every field and to recommend the harvesting of those fields upon which the value of water was lowest in terms of tons of sugar per acre-inch, or dollars worth of sugar per dollars worth of water.

A Hypothetical Case:

The illustration of a principle by an assumed case is unsatisfactory since the making of the assumptions themselves sets up a special case from which it is simple to reason that the general principle lacks local application. Such a case can be so simplified that it may be used as an example which may be elaborated as local conditions warrant. The figures chosen are entirely arbitrary, apply to no particular plantation, but may possibly be close enough to the truth in some to illustrate the scheme.

The first figure at the hand of our evaluator is the overhead which must be borne by each producing acre. For this figure we may, for illustrative purposes only, take $36 per acre per year or $3.00 per acre per month to cover the general sums of overhead plus the salaries which are directly chargeable to field operations. Moreover certain charges accumulate as soon as operations start on any particular acre. The cost of land preparation and planting may be spread over say four crops. When considered in this way the cost of land preparation may be added to the general overhead for that particular acre or field and used as an annual or monthly charge.

But here any possibility of charging each acre a given sum each month ceases. Young fields are being fertilized and cultivated while older ones are long since passed this stage. Moreover irrigation costs will vary not only from field to field but from month to month. Apparently our evaluator must keep a record of the cost of each field, month by month; but this figure is probably already available in the records of our hypothetical plantation. The assumed costs for these operations are indicated in Figs. 1 and 2.

In Figs. 1 and 2 we have two fields of plant cane, one started in April and one in September. Each acre of each field carries the general plantation overhead of $3.00 per acre per month as well as an additional charge of say $0.75 per acre per month to pay interest on the money spent in land preparation and to provide for the complete amortization of this charge in the expected life of the planting. Additional charges of fertilization, irrigation, and cultivation are also reported upon the basis of assumed costs.

In all cases these charges are reported as dollars per acre per month and are so plotted that the total cost of a field as of any date is measured by the area to the left of that date line and below the sequence of upper ordinates.

Harvesting and milling costs have purposely been omitted. Our irrigation evaluator is interested only in field costs and works under the assumption that his job is to put the greatest amount of sugar in the cane for the least cost. Consequently it is necessary to make one more assumption in order that we may establish a figure for the value of sugar in the cane in the field. For this figure, and with the usual reservations, we may use $30.00 per ton leaving perhaps an equal amount to cover the multitude of subsequent charges. One should say at once that an exact figure is not necessary since we are interested in relative values. Regardless of the specific value chosen the results would appear in the same relative position.

If, then, this assumption of a field value of $30.00 per ton for sugar in the cane is tenable we can superimpose curves upon our cost charts which will indicate the rate at which recoverable wealth is accumulating in the fields in question. Here, experimental evidence is only fragmentary but is well enough established for illus-

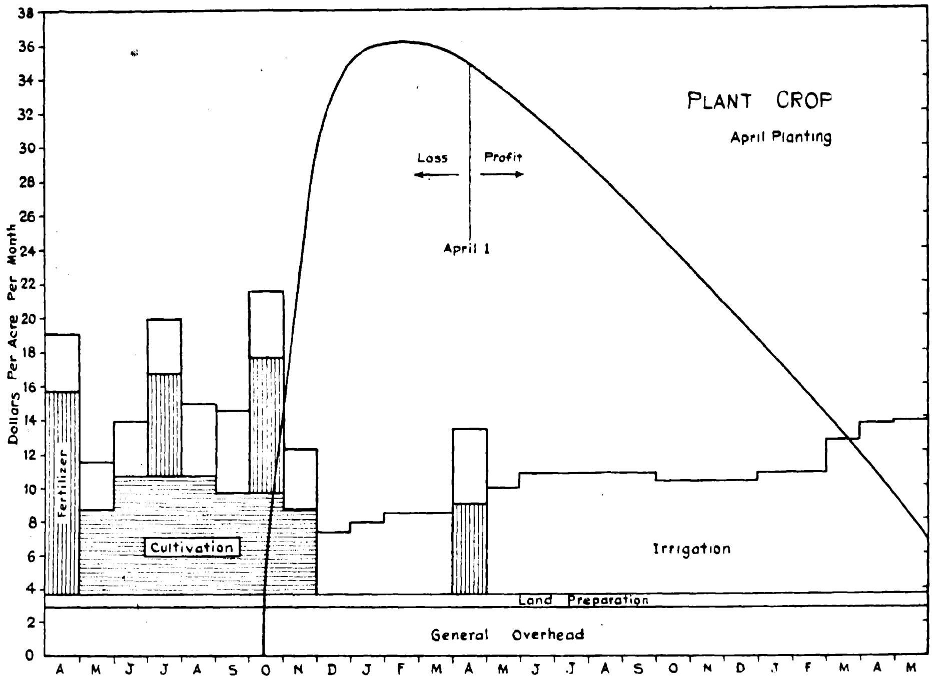

Fig. 1. Basic cost and sugar value chart suggested for determination of relative values of irrigation water. Here the crop is started in April, reaches its maximum rate of sugar production in the following February and begins to show profit on April 1. The assumed costs, upon which the figure is based, are entirely arbitrary and of value only for illustration.

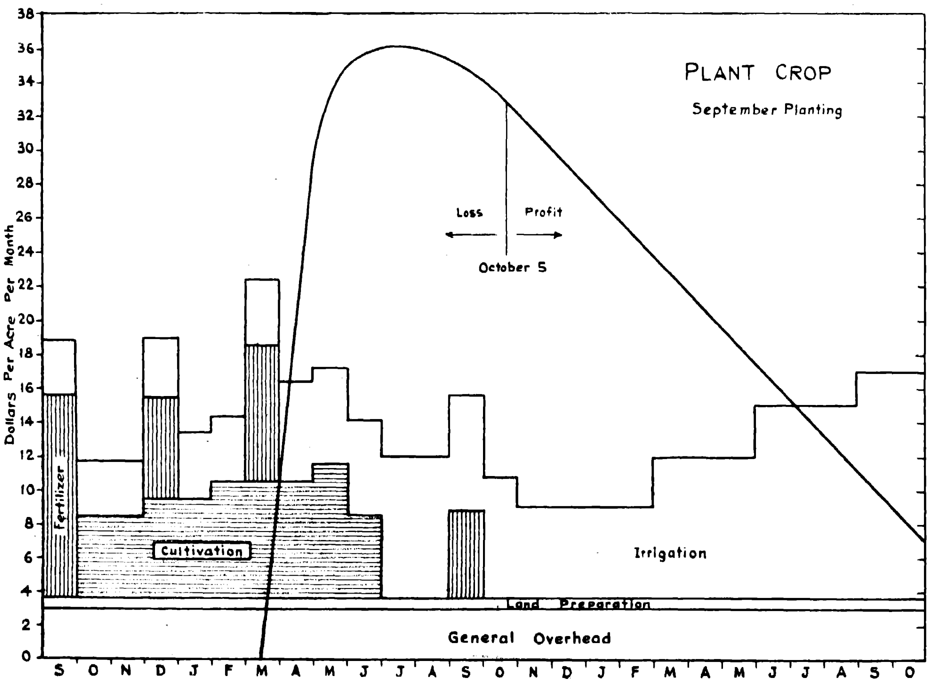

Fig. 2. The possible cost-value relationships for a crop started in September. Here, the time of maximum rate of sugar yield is given as June in place of February and loss turns to profit on October 5 in place of April 1. Again, the basic data are purely hypothetical.

trative purposes. The procedure by which they are secured is well enough fixed to permit our evaluator to keep track of the rate of sugar formation in the fields under his care with sufficient precision.

Again, the curves are plotted against time in months, the vertical ordinate being dollars worth of sugar per acre per month. And, again, the areas under the sugar curves represent the visible wealth in sugar.

Several conclusions can be reached from such curves. We might conclude, for instance, that somewhere between October and November with the April planting the rate at which recoverable sugar is formed is equal to the rate at which money is being spent on the field. Of much greater significance is the conclusion that on April 1 in the case of the April planting the estimate of recoverable sugar equals in value the investment to that date. The corresponding date for the September planting is October 5. Profit can come only when the area under the sugar curve equals the area under the cost curve.

Again, if water be taken as the major single item leading to growth we can estimate the *value* of water in terms of potential sugar production. For instance, in Fig. 1 we see that an application of about $5.00 worth of water in March of the second year has produced $36.00 worth of sugar; this ratio consistently decreases after that date.

The picture prior to the beginning of the formation of recoverable sugar is not so clear. We may assume that if the irrigations were not applied the total investment to date would be lost by the death of the cane, resulting in the necessity of starting over. But as everyone knows some cane varieties can exist for months without available soil moisture although they may make no growth. Or we may credit the irrigation water only with the overhead charges which it is protecting, assuming that the returns from charges for cultivation and fertilization are not lost, but simply postponed. Cost accountants will object to either of these alternatives, but to clarify the illustration let us use the second. During the early age the irrigation water is assumed to have a value equal only to the fixed overhead.

We can then prepare other curves from these data giving the *value* of water in terms of dollars worth of sugar per dollars worth of water for the two cases illustrated. Such curves are given in Fig. 3. It is evident that the value of irrigation water varies not only with the age of the planting but also with the time of the year at which the crop was started. During periods of abundant water supply this conception is of no great value; during periods of real or threatened scarcity it should furnish a valuable guide to the placing of irrigation water in order that the greatest profit may return from its use. For example, in July during the first year of the fall planting a dollars worth of water will produce about five dollars worth of sugar if applied to the September planting. If applied to the young cane its value is almost exactly equal to its cost. The picture changes as time passes. In April of the following year water on the April planting has twice the value of water on the September planting. Moreover, the April planting has just reached the profit-making stage and is making net profit at its greatest rate. In November the lines cross. Here presumably water had equal value on the two locations. Plantation experience will doubtlessly dictate which of the two fields should be favored.

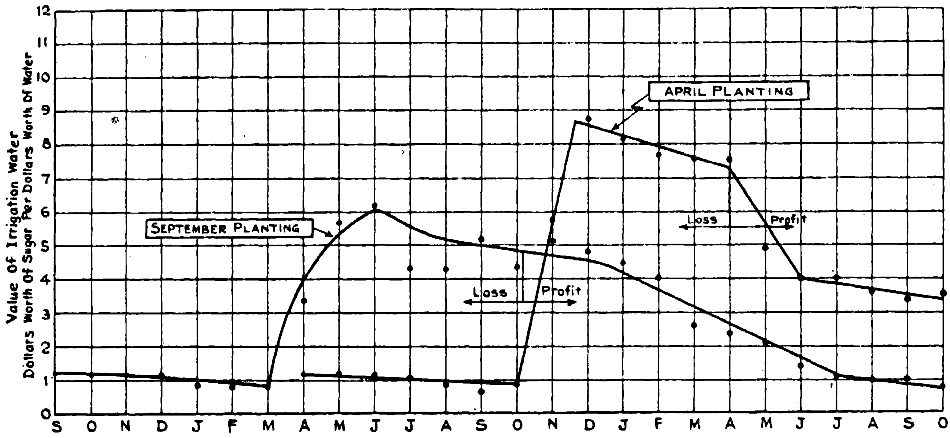

Fig. 3. A hypothetical expression of the *value* of irrigation water as a function of time of year and date of starting. Such curves, if they can be prepared, upon the basis of fact should form valuable guides for irrigation management in time of water shortage.

Discussion:

It is evident that the proposal to trace the value of irrigation water throughout the crop history is based upon assumptions which may not be sound enough to permit its use. This is particularly true with respect to the highly conventionalized curve which purports to represent the rate at which sugar is formed. New varieties, particularly those which may be cut annually, still further complicate the picture insofar as the time-sugar curve must be distorted for such varieties, although its real position is not known.

However, such difficulties do not materially reduce the desirability of such a procedure if the factual background can be improved. Field technique with respect to stalk counts, stalk weights, and the interpretation of juice-quality figures from random samples, has improved so markedly that it is highly probable that the "sugar-in-sight" curve can be built up as time passes without the necessity of making any assumption on this account. Moreover, when once established as a part of plantation routine no significant costs would be involved.

The value of such a procedure can only be determined by trial. It must be well recognized that many unforeseen difficulties would present themselves during such a trial; but with present facilities it is inconceivable that such difficulties would be insurmountable. If a simple but effective scheme for using water during a real or threatened drought can be devised the management would be equipped with still greater flexibility in the administration of one of its most valuable assets.

The correlation between such a scheme of using irrigation water on fields on the basis of positional value and the conventional determination of irrigation desirability by means of cane growth studies or soil moisture history is evident. In operation, concurrently, one might expect extreme economy in irrigation administration.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 15, 1937, TO JUNE 14, 1937

Date	Per Pound	Per Ton	Remarks
Mar. 15, 1937......	3.52¢	$70.40	Cubas, 3.50; Cubas, 3.54.
" 16...........	3.51	70.20	Cubas.
" 19...........	3.45	69.00	Puerto Ricos.
" 24...........	3.505	70.10	Puerto Ricos, 3.50; Cubas, 3.51.
" 25...........	3.54	70.80	Puerto Ricos, 3.53; 3.55.
" 29...........	3.555	71.10	Puerto Ricos, 3.55; Cubas, 3.56.
Apr. 1...........	3.50	70.00	Virgin Islands.
" 2...........	3.4275	68.55	Puerto Ricos, 3.45; Cubas, 3.47, 3.49; Philippines, 3.50.
" 3...........	3.45	69.00	Puerto Ricos.
" 5...........	3.455	69.10	Puerto Ricos, 3.45; Cubas, 3.46.
" 9...........	3.43	68.60	Philippines.
" 12...........	3.45	69.00	Puerto Ricos.
" 16...........	3.505	70.10	Puerto Ricos, 3.50; Cubas, 3.51.
" 19...........	3.505	70.10	Puerto Ricos, 3.50; Cubas, 3.51.
" 20...........	3.505	70.10	Puerto Ricos, 3.50; Cubas, 3.51.
" 22...........	3.47	69.40	Philippines.
" 24...........	3.45	69.00	Puerto Ricos.
" 26...........	3.48	69.60	Cubas.
" 27...........	3.46	69.20	Cubas.
" 28...........	3.455	69.10	Puerto Ricos, 3.45; Cubas, 3.46.
" 30...........	3.40	68.00	Philippines.
May 4...........	3.455	69.10	Puerto Ricos, 3.45; Philippines, 3.45; Cubas, 3.46.
" 6...........	3.45	69.00	Puerto Ricos.
" 14...........	3.39	67.80	Puerto Ricos, 3.38; Virgin Islands, 3.40.
" 15...........	3.38	67.60	Philippines.
" 18...........	3.35	67.00	Puerto Ricos.
June 10...........	3.395	67.90	Philippines, 3.38; Puerto Ricos, 3.40; Cubas, 3.405.
" 14...........	3.4025	68.05	Philippines, 3.40; Cubas, 3.405.

THE HAWAIIAN PLANTERS' RECORD

Vol. XLI FOURTH QUARTER 1937 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Present Trends:

A paper under this title, read at the opening meeting of the sixteenth annual convention of the Association of Hawaiian Sugar Technologists, is given in this number. It deals with synthetic planning as a major need in industrial development.

Fruit Fly Investigations in East Africa:

Although failing in the attainment of its main objective, the introduction of new parasites of the Mediterranean fruit fly into Hawaii, the expedition dealt with in this article has made a valuable contribution to the recorded knowledge of the Trypetidae and their parasites. New host and locality records of well-known species are of value. In addition, according to the News Letter of the United States Department of Agriculture, Bureau of Entomology and Plant Quarantine, Vol. IV, No. 1, p. 27, 1937, the collections made by the expedition, representing 12 species of the genus Ceratitis and 13 species of the genus Dacus, comprise four species new to science in the former genus and five in the latter. There were, besides, two new species of Trypetidae from other genera than Dacus or Ceratitis, and a number of new parasites which are noted in the present article.

Selection of Seedlings:

The relationship of plantation economics to juice quality, closing-in ability, ease of harvesting, and other varietal characteristics is a subject which becomes especially urgent under the prevailing conditions of labor shortage.

In this paper Mr. Conant presents an enlightening analysis of the subject, together with tables which will facilitate further study in this direction.

A New Species of Pyrophorus:

Celebrated in the songs and folklore of the West Indies and Central America for centuries past, the friendly "cucuyos" now have a chance to become equally well

known in regions far removed from their original home. Here is presented an account of the introduction of one species into our own Hawaiian Islands. More recently a closely allied and better known species, *Pyrophorus Luminosus* Illiger, was introduced from Puerto Rico into the Island of Mauritius—it will be interesting to compare the respective records of the two species in their new homes.

Absorption of Mineral Nutrients by Sugar Cane at Successive Stages of Growth:

Sugar cane does not take up all mineral nutrients at constant rates throughout the growth of the crop. While certain elements are absorbed at uniform rates, after the first three months, others are taken up rapidly during the early months of growth, but later at reduced rates. The results of the study lead to the conclusion that the requirement of sugar cane for nitrogen is very pronounced during the early months of growth, but that subsequently much more moderate quantities of the nutrient will suffice to permit optimum growth.

Chemical Analyses as an Aid in the Control of Nitrogen Fertilization:

Supplementing R.C.M. available soil nitrogen investigations conducted on plantations by individual agriculturists and the agricultural and chemistry departments of the Experiment Station have cooperated in conducting a number of pot experimental studies. These experiments were designed to furnish information pertinent to the application to field problems of data determined by rapid chemical analyses. The investigations dealt with two aspects of the nitrogen problem—soil variations and soil-plant relationships.

These studies indicate that in a given soil, the available nitrogen content fluctuates during short intervals and over seasonal periods. Where nitrogen has been applied to soils supporting growing cane, the available soil nitrogen content is usually low due to plant absorption, which may be very rapid. As a result of these studies, a procedure is suggested for the practical application, in fertilization, of available soil nitrogen data obtained by the R.C.M. (rapid chemical method) of analysis.

Trends in Irrigation Practice:

The ever-increasing popularity of long lines in sugar cane irrigation is demonstrated in the survey of irrigation practices made in the summer of 1937. Since 1932 the area irrigated by this method has increased almost fivefold. The use of two-line borders has been widely extended as well.

Although the acreage served by overhead sprinkling has decreased markedly since 1932, it seems highly probable that a small four-acre tract served in this way at Waialua Agricultural Company will point the way to revived popularity.

This paper is the third of a series of three devoted to statistical surveys of sugar cane irrigation in Hawaii. The first two were presented at the Annual Meetings of the Hawaiian Sugar Planters' Association in 1931 and 1932.

Present Trends*

By H. P. Agee

A discussion of present-day trends brings us to consideration of the future—to a contemplation of its problems in an attempt to discern the approach toward their solution.

An intelligent consideration of the future causes us to drop back a little in order to gain our perspective, to align our focus, to establish the composition of what we have before us.

Composition acquires a special meaning as used by artists with reference to their pictures. It has to do with the manner of combining elements to form a whole. It considers balance and coordination. It deals with contrasts homogeneously brought together.

Yet, technologists, no less than artists, are concerned with *the whole of the picture*. In attending to their respective spheres of activity, chemists, engineers, agronomists; botanists, geneticists, pathologists; entomologists, physicians, dietitians; accountants, legal advisors, financiers; are each working upon a section of that whole, yet they cannot consider their work as fragments: they are intimately concerned in appropriately shaping parts—in developing closely related segments of a single comprehensive enterprise.

We call it *agriculture*—this business we conduct in Hawaii, yet we seldom pause to think in terms of what that agriculture has come to be.

As we consider the agriculture of the world generally we become more and more impressed with the fact that we have here something different—we have a new phase of agriculture—a phase that brings the tilling of the soil to the forefront with other lines of activity. We have the large unit, as do manufacturing and transportation and merchandising elsewhere, and thereby the interests of many are pooled for the sake of the opportunities for protection, and the opportunities for advancement that such pooling affords.

Agriculture in Hawaii lives, if we bring it down to a few words, by reason of these three things: (1) cooperation, (2) specialization, (3) coordination. The first of these, *cooperation*, expresses a coming together for united effort. The second, *specialization*, signifies a breaking apart of the whole in a fact-finding search, and a fact-found attack by those specialists particularly qualified for their individual tasks. *Coordination* implies a binding together of those specialties to function as one.

This agriculture merits praise but we do not have the perfect machine. This group is concerned to make it better than it is.

I want to speak of specialization. We have an industry of specialists. I have already named a number of them and either you or I could name more.

* A paper read at the meeting of the Association of Hawaiian Sugar Technologists November 15, 1937.

There are a number of ways in which we might group these specialists of our industry. I like to think of them as, (1) people engaged in developing new basic information, (2) people engaged in finding practical applications of the information we have and in solving the problems of application and adaptation, and (3) people engaged in performing some well-established lines of work or in supervising and checking their performance.

This grouping covers our specialists from the man engaged in the business of freeing a field of sugar cane of its weed growth to the engineer, chemist, or entomologist in his laboratory. There are no sharp dividing lines between the problems of research, application, and performance; no separating gulfs between the issues of investigation, adaptation, supervision and inspection.

The spirit of science should permeate all of them. Science in its clearest and best definitions has nothing about it that is mysterious or obscure. Science means getting at the truth, finding out the facts. Applied science means action based on the facts as they have thus far been revealed.

All of us are specialists in that each of us has undertaken to perform some particular piece of work, and needs to know the reason for that work and the relationship of it to other work that bears directly or indirectly upon it.

Each of us is a scientist in that we are each intimately concerned with facts—with ascertaining the truth and putting it to use.

As specialists we are concerned with the weaknesses of specialization as well as the strength of it. All who have read Alexis Carrel's *Man, the Unknown* (Harper and Brothers, New York and London, 1935) are impressed by his splendid constructive criticism of specialization. He speaks particularly of medicine and medical research but what he says is broadly applicable.

"The science of man," he tells us, "makes use of all other sciences. This is one of the reasons for its slow progress and its difficulty. . . . Obviously, no one scientist is capable of mastering all the techniques indispensable to the study of a single human problem. . . . Specialization is imperative. . . . But it presents a certain danger. . . . Modern civilization absolutely needs specialists. Without them, science could not progress. But, before the result of their researches is applied . . . the scattered data of their analyses must be integrated in an intelligible synthesis."

By synthesis he means the putting together or combining of related parts to form a well-ordered whole, and the work of doing this, Carrel tells us with great positiveness, is essentially the character of work that calls for continual and uninterrupted attention of the individual mind, as distinguished from work that may lend itself to group activity.

". . . a synthesis," he says, "cannot be obtained by a simple roundtable conference of the specialists. It requires the efforts of one man, not merely those of a group. A work of art has never been produced by a committee of artists, nor a great discovery made by a committee of scholars. . . . Today there are many scientific workers, but very few real scientists. This peculiar situation is not due to lack of individuals capable of high intellectual achievements. Indeed, syntheses, as well as discoveries, demand exceptional mental power. . . . Broad and strong minds are rarer than precise and narrow ones."

Carrel continues, "It is easy to become a good chemist, a good physicist, a good physiologist, a good psychologist, or a good sociologist. On the contrary, very few individuals are capable of acquiring and using knowledge of several different sciences. However, such men do exist. Some of those . . . forced to specialize narrowly could apprehend a complex subject both in its entirety and in its parts. . . . If the superiority of this kind of intellect were recognized, and its development encouraged, specialists would cease to be dangerous. For the significance of the parts in the organization of the whole could then be correctly estimated."

Thus does Dr. Carrel in fine emphasis relate the need of specialization, the danger of specialization, and the great importance of giving encouragement to the individual who reaches into several specialties and performs synthetic work—work of putting together in functioning form that which has been developed as a result of analytical study.

Management, we may say, is responsible for this coordinated planning, this piecing together of loose parts. However, an important executive once said, "The office boy has duties, I have interruptions." It is these inevitable unavoidable interruptions that often relegate the all-important business of planning to a secondary or incidental position. This gives us cause to heed what Carrel says of creating a new specialty—that of *synthesis*. This idea is gaining headway. May we list it as a present-day trend?

As an expression of that trend we have a gradually increasing number of assistant-manager appointments. Perhaps as this official becomes engulfed in interruptions we may look for some second assistants on the larger places. I shall be glad if the suggestion brings about some new well-paid positions. I hope there are among us apt candidates.

They should be men who can plan. The fundamental principles of planning are not commonly understood. The schools and universities do not teach planning. They take the accumulated knowledge of mankind and cut it into hundreds of parts and they do it very well. But they do not tell us how to piece parts together in a plan.

The elementary principles of planning are rather simple, yet carried into its further elaborations planning taxes the human mind for all it has to offer. Similarly does mathematics in its further reaches, yet we know that all mathematics is an elaboration of the simple idea that one and one make two.

Lasker set forth the elementary principles of planning as recently as ten years ago.* He tells us a plan conceived in the mind of man is a faulty plan. That is what the matter is with so many of our plans. A human mind has had the effrontery to evolve a plan!

There should, according to Lasker, be a reason for a plan: the reason is a valuation: and the reason for the valuation is again values. The values reveal the plan. The plan is, in effect, a resultant of these values. Failing to develop precise values we have recourse to estimates, and judgment based on estimates trends in the right direction. Also we encounter the so-called intangible values. We can not measure them, yet we must give weight to their influence. Under this head come the human values, the emotional and psychological and prejudicial values.

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* Lasker's Manual of Chess—E. P. Dutton, New York.

It is our quality of so-called common sense that helps us in evaluating intangibles. Intuition is a wonderful thing to possess. It functions best in human relationships. As we carry its use into other fields we find need to give it the support of physical and chemical evaluations.

We undertake an enterprise: we study our values: the values indicate the plan: perhaps certain values are obscure or uncertain: as a result alternate plans develop: choice is made on the basis of comparative estimations.

We proceed with an enterprise: as an army going into battle we contact the inevitable counter forces: we develop information as we go as does the intelligence department of a general staff. There is much that we do not know: we go ahead on the basis of the known and estimated values and seek new values and revised evaluations as we proceed. We give heed to positional values, and recognize that the values of things change according to positions that they occupy in time and space.

This is not new. In some respects it is as old as human effort. Yet few of us follow our values with thoroughgoing persistence. We have not accepted a philosophy of values. It is easy to be led off track by our prejudice; our ego; our preconceived mind-formed plans; by our faulty evaluations; by our conservatism, perhaps, or by our daring.

We let our thinking become fettered by its subject matter. Are we content to remain chemists, mechanical engineers, executives, botanists, electricians, agronomists, accountants? Shall we assign our thinking to circumscribed zones as we assign policemen to beats or postmen to mail routes?

No. Primarily we are specialists in values. Secondarily, we are to draw upon the special training and experience of ourselves and others available for consultation. We are to seek values with which we are intimately concerned regardless of the department of knowledge in which the university has chosen to place them. Pasteur did this. Either he thought broadly because he was a genius, or else he is considered a genius because he thought broadly, precisely, imaginatively.

The difficulties that Carrel describes for a single human mind to reach into several sciences and make use of them synthetically, begin to melt away under this approach. Imagination, that rare quality, reduced to its simplest terms, consists in finding things that fit together and joining them to attain some end. We assert this quality in crude form in solving the jigsaw puzzle. Also we assert it as we develop new ways to gain ground in football; when we find a combination in chess; when we put words or musical notes together in new apt ways. Similarly our great inventions and important discoveries are in last analysis other forms of combination. Perhaps, as with Pasteur, the field of human knowledge is expanded to find basic facts to be brought together.

Creative work, so called, is in reality combinative work as Reti has so ably indicated.

Imagination in industry starts from the premise that current methods and situations are but the phases of today in a moving panorama of events. It differentiates between effort and accomplishment, attempts to strip performance of unessential labor and expense. It forecasts the problems of tomorrow and prepares for them.

The imaginative viewpoint in sugar production takes account of our cultivation practices, fertilization, irrigation, and weed control, in all their varied forms, and

of our choice of sugar cane varieties. It relates these to soil properties, topography, elevation; to cropping cycles, crop lengths, time of crop starting, time of harvesting; relates all in turn to weather variability, makes quantitative measurement of effective temperature and sunlight; it works in terms of the most effective balance between cane tonnage and juice quality; in terms of available man power, available brain power; in terms of mechanical equipment, present and prospective; in terms of costs and market value of our product; in terms of crop quotas; in terms of plantation population welfare and community relationships.

Thereby it encounters a rich and complicated interplay of values from which the plan of action is to be deduced—of necessity a mobile plan to be changed to conform to the mobile values upon which it is based. It studies the whole field of values assiduously, provides investigation and research to explore the outer, darker reaches of that field.

A few days ago I was talking with a man from one of the other Islands. We touched upon trends of the day in sugar production. He felt things were on the decline technologically speaking, that government quotas, labor disturbances, grab harvesting and the consequently poorer mill recoveries, were taking us backward as technologists.

I take issue with that viewpoint considering our problems in the light of bringing to bear upon them our best knowledge and resources. A strategic retreat may call for the finest there is in generalship and an advance merely for the sake of going forward is oftentimes a foolhardy thing to attempt.

Mention has been made of cooperation, specialization, coordination. Let us add that other cardinal need—realization of objective.

Our ultimate objectives remain more or less fixed, our immediate objectives shift and change and thus they tax us for the best we have in planning capacity.

In games we are quick to denote a needed change in immediate objective: we should be equally alert to do so in industry.

A few years ago the Hawaiian plantation was free to market all the sugar it could produce. Each additional ton added to its crop was a welcome ton in so far as the necessary cost of production of the added ton came sufficiently within the selling price to carry a profit. And so we went in for higher and higher yields and higher and higher recoveries.

Then we had the quotas of 1934 and a labor surplus for a time. That threw our objective to the low-cost ton of sugar.

There came an expansion of the quotas, wet years with heavy weed growth, and with them some labor disturbances. Out of this has come a wider use of herbicides. Out of it has come grab harvesting. Only a few months ago the cane harvester was a far-away dream. Then we find that we have in our own back yards, so to speak, equipment that can harvest cane mechanically. Having been blocked all these years by the difficulties of mechanically cutting, trashing, and topping cane, under the new approach we forget all about these stumbling blocks, and grab it, snap it off as best we can, and send it to the mill with its tops and trash, its stones and mud and *honohono.*

It is needless to say to a group of technologists that this approach carries with it a host of new problems. Opinions vary widely on the future of cane grabbing.

Some think of it as a permanent institution in the dry, heavy-yielding lands, and question its application elsewhere. Some look upon it as an expedient in an hour of need, except perhaps for the favored locations. Others optimistically hold that grabbing cane is here to stay—that it is to have wide application—that the difficulties of lower recoveries and congested boiling houses are somehow to be met.

A revolutionary step that cuts the bonds that have held our thinking can lead the way to much that is new in a short time, and no one can predict what another twelve months will bring forth.

Back of this question, as back of all questions, we have our pertinent values—values to be painstakingly sought and estimated and carefully applied to our planning. A plantation that has capacity to produce more sugar than it has the privilege to market, can sacrifice recovery to attain quota under labor limitations. We have in a new form the age old problem of balance—it is an issue of balance in values.

It should be a good gathering—this sixteenth annual meeting of the Association of Hawaiian Sugar Technologists, with so much before us that is new, so much that is in prospect.

Technologists are, of course, greatly interested in high recoveries and maximum yields where the play calls for these. We are equally interested in acceptable sacrifices in recovery or yield per acre, when the game, if well played, brings these into account.

I trust that your deliberations this week will be most instructive and successful and that you will return to your plantations with a better understanding of the problems that are before us, better qualified to discern your objectives, better able to bring about cooperation, specialization and coordinated performance, better fitted to assist in synthetic planning.

Thus you will participate in putting Hawaiian sugar production on a higher plane of excellence, considered from the standpoint of the whole of the picture, and thus will you help to make the plantations better places to live for the thousands who make their homes upon them.

Recent numbers of *Life* (October 18 and 25, 1937) give some inspiring notes about inventor Kettering. These I give in part:

> He remembers he was the "dumbest kid in the whole school" when he started arithmetic in the tumble-down schoolhouse of his youth. He finally completed college in 1904 at the age of 28, threw his diploma in the wastepaper basket, decided he was going to start learning, and took a job with National Cash Register Co. of Dayton, Ohio.
>
> Considered a monkeywrench scientist up to wartime, he is today the idol of young engineers, the pride of General Motors, who made him vice-president in charge of research, and the man most responsible for making the automobile a necessary luxury. He puts the fear of God into businessmen because his mania for progress makes plants and machinery obsolete as soon as they are erected.
>
> Today at 61, Kettering feels he now has the equipment and necessary basic facts to do something.
>
> To science pundits who say "It can't be done," he answers, "The hell it can't!" Then he tries, fails, tries again until finally it is done. He scorns the mystical halo of science, the awkward, ponderous nomenclature of scientific language.

Despite his laughing at "pure science" his versatile mind delves into all its phenomena. "Research," he says, "is finding out what we are going to do when we can't go on doing what we are doing now."

He has seen his visions come true, has new visions. To science he delegates the job of making this a finer world. Says he, "I belong to a group of men who believe the world isn't finished. Nothing is constant but change. We work day after day, not to finish things, but to make the future better . . . because we will spend the rest of our lives there."

In conclusion, gentlemen, I suggest we join that group.

Fruit Fly Investigations in East Africa

By F. A. Bianchi and N. H. Krauss

Here are summarized the findings of the East African Fruit Fly Expedition undertaken by the writers for the United States Department of Agriculture during the latter part of 1935 and the first half of 1936. These findings have already been presented in an official report, but with the addition of identifications for most of the fly and parasite material, only recently completed by the Taxonomic Division of the United States Bureau of Entomology, their usefulness and interest are greatly enhanced.

The four countries visited in the course of the work are dealt with under separate headings.

Tanganyika

Four localities, ecologically widely different, were investigated as follows:

The Tanga Plains:

In the Tanga Plains were investigated the environs of a number of small villages and one large plantation—Sigi-Sigoma. Most of this country is under 1 000 feet elevation and the climate is distinctly tropical with a high average temperature and two clearly marked and rather short rainy periods during the year, March to May and October to December. The supply of fruit was neither very abundant nor greatly varied and consisted mostly of non-indigenous species more or less cultivated. Particularly striking was the fact that in Tanga neither mangoes nor tropical almonds (*Terminalia catappa* Linn.), both very abundant, were ever found infested by fruit flies, although in Hawaii and other countries they constitute important hosts of these pests.

Our stay in Tanga lasted from November 14, 1935 to April 3, 1936 but was interrupted by several short visits to other places.

Following are listed the sources of fruit flies and parasites in this area:

Coccinea sp.: A cucurbitaceous vine with red fruits about two inches long, probably indigenous and not uncommon in weed-grown areas. On one of many occasions when it was examined the fruit yielded *Tridacus vertebratus* Bez. but no parasites.

Psidium guajava Linn. (Myrtaceae): The ordinary guava, not nearly as abundant in Tanga as in Hawaii, and found forming a thicket only on one occasion, proved infested by *Ceratitis colae* Silv. but produced no parasites.

Luffa sp.: Unlike *L. aegyptiaca* this cucurbit had smooth fruit without ribs or warts. It was heavily infested by *Tridacus pectoralis* Walk. but produced no parasites.

Oranges: Shared with mangoes and tropical almonds the distinction of being the most abundant fruit in Tanga and were occasionally found infested by one or more species of Ceratitis which always proved difficult to rear and for which we have no identification.

Cordyla africana Low. (Papilionaceae): Sparsely infested with *Ceratitis cosyra* Walker, of which some 20 per cent of the pupae proved parasitized by *Opius perproximus* Silv.

The East Usambara Mountains:

Visited from November 14 to December 12, 1935, and for shorter periods on several other occasions up to March 1936. Worked mostly in the vicinity of the East African Agricultural Experiment Station, Amani, at elevations of from two to three thousand feet. With the same two short rainy seasons but heavier rainfall than Tanga (80.09 inches, annual mean) and much lower temperature (68.2 F.), this area is heavily wooded and provides a great variety of native as well as introduced species of fruit. Unfortunately the quantity available was not great.

The following fruits were sources of flies and parasites:

Sersalisia usambarensis Engl.: A native sapotaceous tree nearing the end of its fruiting season when we first arrived in Amani. The tree attains a height of 60 feet or more and produces large quantities of an olive-sized fruit—red, brittle-shelled, and extremely attractive to the destructive hornbills, the most conspicuous birds of the region. From about 250 pounds of the fruit we reared *Ceratitis punctata* Wied. and *Ceratitis colae* Silv. and obtained from the mixed pupae of these flies, which we were unable to distinguish before the emergence of the adults, two parasites, *Tetrastichus dacicida* Silv. and *Opius perproximus* Silv.

Psidium cattleianum Sabine. (Myrtaceae): From 20 or 30 pounds of this fruit, the common strawberry guava, all from one cultivated grove, we reared large numbers of *Ceratitis capitata* Wied. and *Ceratitis colae* Silv. The incidence of fly attack was almost 100 per cent, but the per cent of parasitism, by *Opius perproximus* Silv., was practically nil, only nine or ten parasites emerging from all the material.

Psidium guajava Linn. (Myrtaceae): Although even scarcer in Amani than in Tanga, guava trees seemed to produce much larger crops in the former place. We were told the fruiting season lasted from April to October. *Ceratitis colae* Silv. was reared from the fruit. The incidence of attack was high, but no parasites were observed.

Myrianthus arboreus Beauv. (Moraceae): A small indigenous tree with digitately divided leaves and a limited quantity of yellow, annona-like, semi-edible fruit of some four or five inches in diameter. Produced large numbers of both *Ceratitis rubivora* Coq. and *Ceratitis colae* Silv. but no parasites.

Dioscoria macroura Harms. (Dioscoreaceae): A green, irregularly shaped fruit about two inches in diameter, growing on a small tree. Only a small quantity was found from which were reared a few specimens of *Tridacus pectoralis* Walker but no parasites.

Momordica sp. (Cucurbitaceae); Marrow (Cucurbitaceae); Coffee (Rubiaceae); Avocado (Lauraceae); Roseapple (Myrtaceae); and two scarce and undetermined fruits yielded from one to several specimens of fruit fly species for which we have no identifications. The fruit fly or flies reared from marrow showed parasitism by an unidentified parasite.

The West Usambara Mountains:

Visited four days during December 1935. A range more or less parallel to the East Usambaras, separated from them by a deep narrow valley and 70 miles farther inland. In the locality where investigations were conducted, Lushoto, about 5,000 feet elevation, the native forest has been almost entirely displaced by bush and cultivated crops peculiar to the temperate zone, including several species of temperate zone fruits. Among the latter, plums, apples, strawberries, blackberries, mulberries, grapes, and peaches are prominent; but only peaches were obtainable when Lushoto was visited by us. From 40 or 50 pounds of this fruit, with almost 100 per cent incidence of infestation, was reared *Ceratitis colae* Silv. but no parasites.

Arusha:

Visited by Bianchi from March 21 to April 13, and from June 4 to June 23, 1936. With an elevation approximately the same as that of Lushoto, Arusha is ecologically different because of its remoteness from the coast (350 miles) and its proximity to the great extinct volcanoes Meru and Kilimanjaro, the latter being perennially snowcapped. Mean annual temperature is lower (64.8 F.) than in Lushoto and rainfall is less (44.18 mean annual inches) with two short and poorly defined rainy seasons separated by two drier periods. The region is noted as a coffee-growing center and also produces small quantities of the same temperate zone fruits found in Lushoto. As neither the vast uncultivated plains within easy reach of the town nor the equally accessible and beautifully wooded slopes of Mt. Meru proved bountiful sources of native fruits, most of the investigations dealt with these temperate zone fruits. The results follow:

Peponium sp.: A semi-edible Cucurbit, orange-colored when fully matured, somewhat like a common cucumber and growing on similar vines; a common and conspicuous component of brush thickets covering large areas of fallow land. This very abundant fruit showed high incidence of infestation by *Dacus eclipsis* Bez., *Tridacus pectoralis* Bez., and *Tridacus punctatifrons* Karsch. but never any parasites.

Undetermined Cucurbit: Fruits small, about one-half inch in diameter, pear-shaped, light green when unripe, with white longitudinal stripes when mature, growing on a roughly pubescent, small-leafed vine. Only two vines seen, one on the plains near Arusha, the other 3,000 feet higher up the slope of Mt. Meru in dense forest. From the latter was reared *Tridacus humeralis* Bez. which was attacked by *Tetrastichus giffardi* Silv. and an undetermined species of Opius. Both the incidence of fly attack and the percentage of parasitism were high.

Oranges and Common Guavas: Fairly abundant; yielded *Ceratitis colae* Silv. Fly incidence was high in guavas, very low in oranges. No parasites were reared from either fruit.

Himalayan Blackberries and Peaches: Both obtainable only in small quantities; yielded *Ceratitis rubivora* Coq. but no parasites.

Psidium cattleianum Sabine: The ordinary strawberry guava; few and widely scattered trees in private gardens; in one locality proved infested by *Ceratitis capitata* Wied. Ten pounds of the fruit with an estimated fly incidence of 80 per cent yielded eight specimens of *(Hedylus) Opius giffardi* Silv.

Coffee: It was said that ripening of the 1936 crop was held back by a protracted spell of cold weather. Due to that fact, perhaps, it was not possible to rear any of the parasites mentioned by the late A. H. Ritchie (Annual Report of the Tanganyika Department of Agriculture for 1934, page 77). From about 150 pounds of berries, hand-picked mostly from three particular sources, were reared four or five hundred flies of two species, *Ceratitis rubivora* Coq. and *Ceratitis colae* Silv. The incidence of attack was not high but is said to rise enormously as ripening of the crop progresses, the abundance of fly larvae sometimes hindering the depulping process.

ZANZIBAR

Zanzibar is an island with a surface extension of 640 square miles and a highest elevation of 440 feet. It lies only 25 miles east of Tanganyika and has a climate very similar to that of Tanga, but because of its dense population and other reasons the island enjoys ecological conditions different than Tanga's and provides a much greater variety and abundance of cultivated fruits. Unfortunately it soon became evident here, as elsewhere, that cultivated fruits were not often infested with fruit flies and that these, in cultivated fruits, were seldom heavily parasitized.

Zanzibar was visited by Bianchi from December 3 to December 12, and by Krauss from December 18, 1935 to January 5, 1936.

Out of a very long list of fruits available, only the following proved infested:

Psychotria sp. (Rubiaceae): A small red berry growing on vines near the north end of the island; locally called "Umjoma"; probably indigenous; quite scarce. Yielded a species of Ceratitis new to science, parasitized by a species of Opius, also new to science, and by *Spalangia afra* Silv.

Psidium guajava Linn: Common guava; scarce; the trees did not produce abundantly and were found mostly near habitations, more or less under cultivation. Yielded *Ceratitis capitata* Wied. and *Ceratitis colae* Silv. but no parasites.

Luffa aegyptiaca Mill., *Momordica charantia* Linn., and cucumber (Cucurbitaceae) were all abundant and heavily infested with *Tridacus pectoralis* Walk. From the first no parasites were obtained, but the second yielded a single specimen of a Dirhinus new to science and the third a single specimen of *Spalangia afra* Silv.

Pumpkin of undetermined species (Cucurbitaceae): Bought in the market; scarce. Infested with *Dacus brevistylus* Bez. from which were reared *Opius perproximus* Silv. and *Spalangia afra* Silv.

KENYA COLONY

Nairobi and the highlands accessible from that town by rail were worked by Krauss between April 6 and June 23, 1936. Nairobi, particularly, proved a very rich source of useful fruits and berries of native and introduced species. Of these nearly one hundred species were examined, but only those from which flies or parasites were reared are given in the accompanying table.

A species of Strychnos, of the family Loganiaceae, not shown in the table, was the most productive source of fruit flies in Nairobi, and perhaps the most likely source of a useful parasite found during our whole expedition. This fruit is a small orange-colored drupe which is produced in great quantity on a medium sized

tree much used in Nairobi and its outskirts for shade and ornament. Showing a very high incidence of fly attack and a considerable percentage of parasitism the fruit provided a large number of parasitized pupae which we endeavoured to carry along with us on our return to the United States but which, due to the duration of the voyage and other circumstances, failed to survive. Had our expedition lasted longer, Strychnos would undoubtedly have provided additional material for air shipments of parasites which could have reached America in good shape, where earlier shipments made from Tanga had failed because of their necessarily small size and our own inexperience of the complexities of African communications. Unfortunately, however, our somewhat hurried departure from Nairobi took place two or three weeks before the height of the fruiting season of Strychnos and before parasites had begun to emerge in quantities sufficient for shipment.

The parasites found in Strychnos were *Opius perproximus modestor* Silv., *Opius fullawayi* Silv., Opius of undetermined species, (*Bracon*) *Microbracon celer* var., *Tetrastichus giffardianus* Silv., *Tetrastichus n. sp.* near *giffardii* Silv., and an Encyrtid of undetermined species. *Opius perproximus modestor* Silv. was the most abundant among the Braconidae and the new species of *Tetrastichus* near *giffardii* Silv. was by far predominant among the Chalcids. Most of our parasite material emerged during the first week on board our homeward-bound ship and all the parasites were reared from a single species of fly, *Ceratitis nigra* Graham. The percentage of parasitism by all the species was around 50 per cent, but the great quantity of our material and the difficulties of handling it in our crowded cabins prevented us from making accurate counts of the relative abundance of each species.

The table showing other fly-infested fruits of Kenya follows:

Date 1936	Locality	Fruit Host	Fly Species Reared	Parasites Reared
May 2	Meru	*Solanum naumanni* Engl. (Solanaceae)	*Ceratitis n. sp.*	None
May 3	Meru	Himalayan blackberry (Rosaceae)	*Ceratitis rubivora* Coq.	*Opius fullawayi* (Silv.)
			Ceratitis colae Silv.	Opius undetermined sp.
May 3	Nanyuki	*Coffea arabica* Linn. (Rubiaceae)	*Ceratitis capitata* Wied.	None
May 16	Kakamega	*Solanum* prob. *indicum* Linn. (Solanaceae)	*Ceratitis n. sp.*	*Opius fullawayi* (Silv.)
May 18	Kakamega and			Opius undetermined sp.
	Londiani	*Melothria sp.* (Cucurbitaceae)	*Tridacus n. sp.* near *chrysomphalus*	None
May 16	Londiani	*Rubus sp.* (Rosaceae)	*Ceratitis rubivora* Coq.	None
May 20	Nanyuki	*Cissus nananquensis* (Ampelidaceae)	Undetermined Trypetid	None
April	Nairobi	*Acokanthera longiflora* Stapf. (Apocynaceae)	*Ceratitis capitata* Wied.	*Opius perproximus* Silv.
			Ceratitis cosyra Walker.	*Opius humilis* Silv.
			Ceratitis bremii Guer-Men.	*Tetrastichus giffardii* Silv.
April	Nairobi	Loquat	*Ceratitis capitata* Wied.	None
			Ceratitis colae Silv.	None
April	Nairobi	*Tacsonia sp.* (Passifloraceae)	*Ceratitis capitata* Wied.	None
April	Nairobi	*Duranta plumieri* Jacq. (Verbenaceae)	*Tridacus n. sp.*	*Opius fullawayi* (Silv.)
				Opius perproximus Silv.
April	Nairobi	*Doryalis caffra* Warb. (Flacourtiaceae)	*Ceratitis capitata* Wied.	Miscogasteridae—
			Ceratitis colae Silv.	genus near Halticopter
April	Nairobi	*Podocarpus gracilior* Pilger (Podocarpaceae)	*Ceratitis colae* Silv.	None
April	Nairobi	*Warburgia ugandensis* Sprague (Canellaceae)	*Ceratitis cosyra* Walk.	*Opius perproximus* Silv.
April	Nairobi	*Rawsonia usambarensis* K. Schum. (Flacourtiaceae)	*Ceratitis colae* Silv.	None
			Ceratitis rubivora Coq.	None
April	Nairobi	*Solanum naumannii* Engl. (Solanaceae)	*Ceratitis n. sp.*	*Opius perproximus* Silv.
April	Nairobi	*Teclea trichocarpa* Engl. (Rutaceae)	*Ceratitis capitata* Wied.	*Opius humilis* Silv.
				Opius fullawayi (Silv.)
April	Nairobi	*Vangueria sp.* (Rubiaceae)	*Ceratitis capitata* Wied.	None
April	Nairobi	*Acokanthera schimperi* Schweinf. (Apocynaceae)	*Ceratitis bremii* Guer-Men.	None
May and June	Nairobi	*Brucea antidysenterica* Miller (Simarubaceae)	*Ceratitis capitata* Wied.	*Opius fullawayi* (Silv.)
				Opius undetermined sp.
May	Nairobi	*Berberis holstii* Engl. (Berberidaceae)	*Ceratitis capitata* Wied.	None
May and June	Nairobi	*Momordica sp.* (Cucurbitaceae)	*Tridacus punctatifrons* Karsch.	None
May	Nairobi	*Deinbollia sp.* (Sapindaceae)	*Ceratitis rubivora* Coq.	Opius undetermined sp.
May	Nairobi	Himalayan blackberry (Rosaceae)	*Ceratitis rubivora* Coq.	None
June	Nairobi	*Coffea arabica* Linn. (Rubiaceae)	*Ceratitis capitata* Wied.	*Opius humilis* Silv.
June	Nairobi	*Melothria sp.* (Cucurbitaceae)	Dacinae undetermined sp.	None

Uganda

The Crown Colony of Uganda was visited by Bianchi from April 20 to June 2, 1936. Eight or nine days were spent in the Lake Victoria Region (Entebbe, Kampala, and Jinja) which from the first appeared but scantily provided with fruit; nearly three weeks were spent at the Busingiro Forest Station, about midway between Lakes Kyoga and Albert, on the arterial that connects East Africa with the Belgian Congo; the rest of the time was spent in a tour of the West Nile District of the Northern Province. The outskirts of Busingiro Forest; certain areas of the West Nile District which very roughly coincided with the western escarpment of the Nile River Basin; and the plains of Soroti proved the most bountiful sources of fruit in the Colony. Had time been available to return to these areas at a different season and more leisurely, it is probable that valuable results could have been obtained. As it was, however, the visit to Uganda seemed to be ill timed in relation to the fruiting seasons of many of the most likely looking available species of fruit.

The Shea butter tree, *Butyrospermum niloticum* Kotschy (Sapotaceae) proved one of the disappointments of the trip. Reported as a host of *Ceratitis giffardii* Bezzi in the French Sudan (Silvestri; an expedition to Africa in search of the natural enemies of fruit flies) it was to be expected that Butyrospermum would harbor the same or other fruit flies in Uganda. But although the fruit is to all appearances an ideal fruit-fly host and although it could be collected fully matured and in great quantities in several localities of the West Nile District, no sign of fly attack was ever seen on it.

Tamarind trees, *Tamarindus indica* Linn. (Caesalpiniaceae), were a very common and conspicuous part of the flora in certain areas near Pakwach, West Nile District, and although the height of the fruiting season was past some fruit remained on them. None of this proved infested, however, although on one occasion a Ceratitis was seen resting on the foliage of a tree.

Out of a long list of potential hosts only the following fruits yielded either flies or parasites:

Chrysophyllum albidum Don. (Sapotaceae): Tall, fringe-of-the-forest tree with brown, semi-edible fruits about the size of a small apple. Only a few specimens collected on the outskirts of Busingiro Forest. Showed a small incidence of attack by *Ceratitis colae* Silv. and *Ceratitis punctata* Wied. and produced a single specimen of an Opius new to science and two specimens of Cynipideae of the genus Ganaspis.

Solanum naumannii Engl. (Solanaceae): Found only on the edge of Busingiro Forest, seemingly at the end of the fruiting season. Ten pounds of the fruit, a small berry, showed almost a 100 per cent incidence of attack by a Ceratitis new to science but yielded only 21 specimens of *Tetrastichus* probably *oxyurus* Silv., and only four specimens of *Opius fullawayi* (Silv.).

Psidium guajava Linn. (Myrtaceae): Found mostly scattered among bush of uncultivated areas near Kampala, Jinja, and Busingiro, but not seen east of the latter point. In Busingiro this fruit was attacked by *Ceratitis colae* Silv. and *Ceratitis rubivora* Coq. but produced no parasites.

Eugenia jambos Linn. (Myrtaceae): Common rose apple. From the fruit of cultivated trees in Busingiro were reared specimens of *Ceratitis colae* Silv. but no parasites.

Persea gratissima Gaertn. (Lauraceae): Avocado; a light green, moderately thin-skinned variety was found unusually abundant in the town of Jinja growing on a small tree evidently planted for ornamental purposes along the streets and in gardens, but this variety showed no attack by fly. From a single specimen of a thicker skinned and much scarcer variety found in Busingiro were bred a few *Ceratitis rubivora* Coq. but no parasites.

Myrianthus arboreus Beauv. (Moraceae): More abundant in Busingiro than in Amani, Tanganyika, but evidently not as heavily attacked by fly. Yielded *Ceratitis colae* Silv. but no parasites.

Vitex either *madiensis* Oliv. or *schweinfurthii* Bak. (Verbenaceae): Semi-edible, olive-like, growing on bushy trees up to ten feet in height. Moderately abundant in several places on the west escarpment of the Nile River Basin. Five pounds collected near Amugo, West Nile District, yielded ten specimens of *Tridacus pectoralis* Walk. but no parasites.

Capparis erythrocarpa Isert. (Capparidaceae): A very thorny rambler with a red fruit similar in size and structure to a small granadilla. Moderately abundant in several places both east and west of the Nile. More than 100 fruits collected near Soroti, Northern Province, yielded about 40 specimens of *Themarictera laticeps* Loew. but no parasites.

Some Important Factors to Consider in Selecting Seedlings

By Raymond K. Conant

The program of raising, selecting, and testing of new varieties of sugar cane will probably be carried on as long as the cane sugar industry continues to exist, for the reason that we will never be satisfied with the varieties we have, and will persist in our endeavor to find canes which will improve our yields and reduce our costs.

The raising of new varieties is not difficult today, since we have at our disposal the knowledge gained from scientific research, which has developed the technique of cane breeding to a point where this part of the program is comparatively easy. Selecting the best of these new varieties, and deciding which ones will prove most profitable to the plantations, is still another matter. Herein lies the difficulty. The question of what factors should be considered foremost in variety selection is one which deserves a great deal of study. We know what qualities we want in our seedlings, but these qualities never seem to be combined in one variety. In other words, we find both good and poor qualities in all of our varieties, and the question of what qualities we should emphasize as being of foremost importance is one which is open to debate. The fieldmen want disease-resistant varieties that grow fast, close-in early, ratoon well, hold-over, and are easy to harvest. The millmen want canes with excellent juices, and a minimum of trash. Their varieties must be easy to crush, and must have juices that clarify, and boil properly. Proper fiber content, and other minor qualifications are desirable in varieties from the millman's point of view.

Disease resistant varieties that close-in fast and ratoon well are not difficult to find now, since many of the new varieties carry enough of *Saccharum sinense*, *Saccharum spontaneum*, or *Saccharum robustum* blood to insure great vegetative vigor and disease resistance. But a great many of these canes have rather poor juice quality, or are hard to harvest because of small stalks and their tendency to be trashy. These canes are usually looked upon with great favor by fieldmen up until harvesting operations commence. The difficulties that are often encountered in harvesting and milling these canes cause both fieldmen and millmen to be apprehensive of the value of these varieties, and the claim is often made that what labor and money is saved in cultivation by these fast-growing, rapid closing-in canes is lost because of increased labor requirements in harvesting, and added transportation and milling expense.

If we look at this problem from the fieldman's viewpoint, we may be inclined to discount juice quality, and place emphasis on yields and labor requirements for cultivation, and the amount of labor required for harvesting. The millman may see the problem only from the standpoint of juice and milling qualities, and may disregard the question of cultivation. He may consider increased yields to be of no value if these increases are accompanied by poor juice, poor milling qualities, etc.

Briefly, then, the type of canes that we all want must have the following qualifications:

1. Disease resistance.
2. Great vegetative vigor:
   (a) good germination from seed;
   (b) good ratooning;
   (c) good closing-in.
3. Good cane yields.
4. Reasonably easy to harvest.
5. Good juice.
6. Minimum trash.
7. Good milling, including all of the ramifications.

Preliminary selection work is based almost entirely on appearances. We look for healthy-appearing canes with great vegetative vigor, and often consider stalk size of secondary importance. After we have spread the outstanding varieties from the preliminary selection to a point where sufficient seed is available, it is customary to plant these canes in variety tests which usually have 5 or more replications in comparison with some standard cane of known reputation. Observational notes are taken during the progress of the experiments, regarding vegetative vigor, health, etc., and when the tests are harvested at maturity careful data are obtained in regard to cane yields, juices, and sugar yields. Observational notes are taken at this time relative to weed suppression, holding-over qualities, disease resistance, insect damage, stalk size, etc., but stalk size may be only casually mentioned if cane and sugar yields are good.

By the time that the replicated or "Grade A" tests are harvested, we have a fair idea regarding disease resistance, vegetative vigor, yields, juices, and trash, but we have very little information on the harvesting qualities of the varieties in the tests, and know practically nothing regarding the milling qualities of the varieties.

That the latter two qualities are of the utmost importance cannot be denied, but ways and means of determining or measuring the importance of these two factors are not at our disposal until the varieties are planted to field-scale proportions, and even after we have the varieties in field plantings it is sometimes difficult to determine just how or to what extent these two factors affect our costs.

After a variety has been planted to and harvested from 50 acres or more, sufficient data should be available relative to cultivation, harvesting, and transportation costs, and enough knowledge regarding the milling should be at hand to enable one to calculate with some degree of accuracy the actual value of the variety in question. With this in mind, the writer has prepared four tables relevant to labor requirements and costs that may be involved with these 4 operations when quality ratios vary from 6 to 14 and when cane yields vary from 50 to 100 tons per acre.

The data in these tables should not be construed as being representative of labor requirements and costs for any particular plantation. They were prepared for this report merely for the purpose of serving ~~as~~ a basis upon which certain hypothetical problems could be discussed, pertinent to the variety question in *wet, unirrigated* districts where weed control is a major problem, and burning before harvesting can seldom if ever be done. However, the tables are flexible enough to take care of a

variety of conditions, and it is possible that they might be applicable to seedling problems identified with other conditions.

The tables used in this report pertain, for the sake of simplicity, to a crop of 10,000 tons of sugar.

Assume now that a 50-acre field of variety "A" has been harvested, and the following data relative to this variety have been obtained:

1. Cultivation—15 men per acre.
2. Cane yield—90 tons per acre net.
3. Q. R.—11.
4. Harvesting rather difficult:
   (a) Cutters average—5 net tons cane per man.
   (b) Loaders average—11.5 net tons cane per man.
   (c) Increased rates given cutters and loaders.
5. Tare—14 per cent.
6. Transportation costs higher than average due to trash and added cane.
7. Milling—considered poor, because of trash and poor juice.

Data from fields in the standard variety "X" supply the following information:

1. Cultivation—30 men per acre.
2. Cane yields—60 tons per acre net.
3. Q. R.—9.
4. Harvesting:
   (a) Cutters average 7.5 tons net cane per man.
   (b) Loaders average 15 tons net cane per man.
5. Tare—8 per cent.

The above information tells us that we are saving 15 men per acre in cultivation with variety "A," that we are getting more cane and more sugar per acre from variety "A," despite poorer juices, but it also tells us that we are using more men for harvesting, and are increasing our transportation and milling costs due to poor juice and increased trash with variety "A." The problem, then, is to determine whether the saving in cultivation, and the increased yields will offset the increased harvesting, transportation, and milling costs.

Example 1:

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	11	9
TC/A	90	60
TS/A	8.18	6.66
Tare, Per Cent	14	8
Harvesting:		
TC per man cut and load	3.5	5.0
TS per man cut and load	.31818	.5555
Delivery cost per ton of cane	$1.40	$1.30
Manufacturing cost per ton of sugar	$2.14	$1.65

The above data will be explained as we go along.

Turn first to *Table I—Cultivation* and obtain the following:

	Variety "A"	Variety "X"
TC/A	90	60
Q. R.	11	9
M/A	15	30
Ac's/10,000 TS	1,222	1,500
M/10,000 TS	18,330	45,000
Cost per 10,000 TS at $1.50 per man	$27,495	$67,500

Before turning to Table II, a brief explanation will be given of the term TC/M (tons of cane per man cutting and loading, or cutting and packing where cane is transported by flumes) as used in this paper.

Variety "A"—1 man cuts 5 tons net cane per day
1 man loads 11.5 tons net cane per day

or 2.3 men cut 11.5 tons net cane per day
1 man loads 11.5 tons net cane per day

so 3.3 men cut and load 11.5 tons net cane per day
or 1 man cuts and loads 3.5 tons net cane per day

Variety "X"—1 man cuts 7.5 tons net cane per day
1 man loads 15 tons net cane per day

or 2 men cut 15 tons net cane per day
1 man loads 15 tons net cane per day

so 3 men cut and load 15 tons net cane per day
or 1 man cuts and loads 5 tons net cane per day

For simplicity, the cutting and loading will be considered hereafter in this paper as one operation, and any reference to tons of cane per man in the harvesting, should be interpreted as tons of cane per man cutting and loading. This figure can be obtained as illustrated above.

Now we refer to *Table II—Harvesting,* and find the following:

	Variety "A"	Variety "X"
TC/M	3.5	5
Q. R.	11	9
TS/M	.31818	.5555
TC/A	90	60
TS/A	8.18	6.66
M/10,000 TS	31,429	18,000
Ac's/10,000 TS	1,222	1,500
TC/10,000 TS	110,000	90,000

Table III—Transportation, Cutting and Loading Costs:

Assume that it costs $1.30 per ton of cane for delivery at the mill for standard variety "X," and that because of more difficult cutting and loading we have to pay the cutters 5 cents more per ton of cane for cutting variety "A," and the loaders 4 cents more per ton of cane for loading variety "A," and that due to trash, etc., it

costs 1 cent more per ton of cane to transport variety "A." Then we have $1.30 per ton of cane to deliver variety "X" and $1.40 per ton of cane to deliver variety "A."

	Variety "A"	Variety "X"
Q. R.	11	9
TC/10,000 TS	110,000	90,000
Cost of delivery per ton of cane	$ 1.40	$ 1.30
Cost of delivery per 10,000 TS	$154,000	$117,000

Table IV—Manufacturing:

	Variety "A"	Variety "X"
Q. R.	11	9
Tare	14%	8%
Cost per ton of sugar	$ 2.14	$ 1.65
Cost per 10,000 TS	$21,400	$16,500

Combining the data obtained from the four tables we get:

	Variety "A"	Variety "X"
Cultivation	$ 27,495	$ 67,500
Harvesting and transportation or delivery	154,000	117,000
Manufacturing	21,400	16,500
	$202,895	$201,000
	— 201,000	
	$ 1,895	

(19 cents per ton of sugar against variety "A")

In regard to labor we find from Tables I and II:

	Variety "A"	Variety "X"
Cultivation	18,330 men per 10,000 TS	45,000 men per 10,000 TS
Harvesting	31,429 men per 10,000 TS	18,000 men per 10,000 TS
Total	49,759 men per 10,000 TS	63,000 men per 10,000 TS
		—49,759
		13,241

(13,241 man-days saved in favor of variety "A.")

So we have a cost of 19 cents per ton of sugar against variety "A," but a substantial saving in labor in favor of variety "A."

Example 2:

If the Q. R. of variety "A" were 13 instead of 11, we would find the following from the tables:

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	13	9
TC/A	90	60
TS/A	6.92	6.66
Tare, Per Cent	14	8
Harvesting:		
TC/M	3.5	5.0
TS/M	.2692	.5555
Delivery cost per ton cane	$1.40	$1.30
Manufacturing per ton sugar	$2.14	$1.65

	Variety "A"		Variety "X"	
	Men	Dollars	Men	Dollars
Cultivation	21,660	32,490	45,000	67,500
Harvesting	37,147	.....	18,000	.....
Delivering	.....	182,000	....	117,000
Manufacturing	.....	25,300	.....	16,500
	58,807	$239,790	63,000	$201,000
		—201,000	—58,807	
		$ 38,790	4,193	

($3.88 per ton of sugar against variety "A" and a saving of only 4,193 man-days in favor of variety "A" with Q. R. of 13.)

Example 3:

Assume that variety "A" has Q. R. of 11 against 9 for "X," and that cultivation requirements are 15 men per acre for "A" and 30 men per acre for "X," and that "A" has large stalks and can be harvested as cheaply, and as easily per ton of cane as "X," but that due to "A" having poorer juice than "X," manufacturing costs are slightly higher for "A." Tare 8 per cent for both varieties.

Referring to the tables we find:

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	11	9
TC/A	90	60
TS/A	8.18	6.66
Tare, Per Cent	8	8
Harvesting:		
TC/M	5.0	5.0
TS/M	.45454	.5555
Delivery cost per ton cane	$1.30	$1.30
Manufacturing per ton sugar	$2.03	$1.65

	Variety "A"		Variety "X"	
	Men	Dollars	Men	Dollars
Cultivation	18,330	27,495	45,000	67,500
Harvesting	22,000	.....	18,000	.....
Delivering	.....	143,000	.....	117,000
Manufacturing	.....	20,300	.....	16,500
	40,330	$190,795	63,000	$201,000
			—40,330	—190,795
			22,670	$ 10,205

($1.02 per ton of sugar in favor of variety "A" and 22,670 man-days in favor of variety "A.")

Example 4:

Same as Example 3 with the exception that the Q. R. of "A" is 13.

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	13	9
TC/A	90	60
TS/A	6.92	6.66
Tare, Per Cent	8	8

Harvesting:		
TC/M	5.0	5.0
TS/M	.3846	.5555
Delivery cost per ton cane	$1.30	$1.30
Manufacturing per ton sugar	$2.38	$1.65

	Variety "A"		Variety "X"	
	Men	Dollars	Men	Dollars
Cultivation	21,660	32,490	45,000	67,500
Harvesting	26,000	.....	18,000	.....
Delivering	.....	169,000	.....	117,000
Manufacturing	.....	23,800	.....	16,500
	47,660	$225,290	63,000	$201,000
		—201,000	—47,660	
		$ 24,290	15,340	

($2.43 per ton of sugar against variety "A" and 15,340 man-days in favor of variety "A.")

Example 5:

Assume that variety "B" has excellent juice, but is slow in closing-in, and is a poor ratooner. Q. R. of "B" = 7 and "C" = 9. Cultivation requirements 40 men per acre for "B" and 20 men per acre for "C." Tons cane per man cutting and loading = 5 for both varieties, and tare = 8 per cent for both varieties. Delivery costs $1.30 per ton of cane for both varieties. Cane yields 50 TC/A for "B" and 60 TC/A for "C."

	Variety "B"	Variety "C"
Cultivation: Men per acre	40	20
Q. R.	7	9
TC/A	50	60
TS/A	7.14	6.66
Tare, per cent	8	8
Harvesting:		
TC/M	5.0	5.0
TS/M	.71428	.5555
Delivery cost per ton cane	$1.30	$1.30
Manufacturing per ton sugar	$1.28	$1.65

	Variety "B"		Variety "C"	
	Men	Dollars	Men	Dollars
Cultivation	56,000	84,000	30,000	45,000
Harvesting	14,000	.....	18,000	.....
Delivering	.....	91,000	.....	117,000
Manufacturing	.....	12,800	.....	16,500
	70,000	$187,800	48,000	$178,500
	—48,000	—178,500		
	22,000	$ 9,300		

(93 cents per ton of sugar and 22,000 man-days against variety "B.")

Examples similar to those given above could be cited without end, but the purpose here is to bring out certain factors that are of importance in seedling selection work. It will be noted that juice, or Q. R. as we have considered it in this paper,

enters every phase of the problem as considered, i. e., Q. R. affects cultivation costs and labor requirements for cultivating, indirectly, through the effect on area; it affects harvesting through the *tons of sugar cut and loaded per man;* it affects transportation through the amount of cane to be handled to produce a given amount of sugar, and it affects manufacturing in the same way.

Vegetative vigor affects cultivation requirements, yield, and consequently area; and size of stalk affects harvesting directly, and transportation and manufacturing indirectly through tare and weight per unit of volume. That is, we would expect a large-stalk cane to have less trash, and weigh more per unit of volume than a small-stalk variety.

Yield of cane would naturally affect all four phases, but the effect of yield of cane is dependent upon Q. R.

Since cane yields are associated with vegetative vigor, it would seem that these two qualities could be considered together, but Q. R. and size of stalk may be considered separately or together. That is, poor juices can be excused to some extent in a large-stalk cane, but in a small-stalk cane that is difficult to harvest, poor juices may increase costs even where a saving is made in cultivation.

Since the purpose of raising sugar cane is to produce sugar, it goes without saying that juice is a very important factor to consider in variety selection work, but the data in Example 3 indicate that a poor-juice cane may be profitable to raise providing it has great vegetative vigor, and has large stalks, so that the harvesting of it is reasonably easy; and providing also that the transportation system and factory can handle the added cane needed to produce a given amount of sugar; and vice versa, a good-juice cane (Example 5), that may be expensive to cultivate, may not be as profitable to raise as a poorer-juice cane that may be reasonably cheap to cultivate.

Note:

The data on costs used in this paper do not take into account such items as repairs, depreciation, rentals, etc., so that the figures are somewhat lower than the actual costs involved in the four operations considered. It was felt that in order to be clear, the tables and data would need to be as simple as possible, so in order to avoid confusion no attempt was made to have the data include all of the expenses incidental to actual conditions. However, since most of the items not included are fixed charges, the operating costs used in the tables should be sufficient for the purpose we have in mind.

The data on cultivation requirements are supposed to be applicable to ratoon fields only.

TABLE I

MAN-DAYS REQUIRED TO CULTIVATE AN AREA SUFFICIENT TO PRODUCE 10,000 TONS OF SUGAR

TC/A	Q. R.	TS/A	Ac's Per 10,000 TS	Total Man-Days At 5 M/A	10 M/A	15 M/A	20 M/A	25 M/A	30 M/A	35 M/A	40 M/A	45 M/A	50 M/A
50	6	8.33	1,200	6,000	12,000	18,000	24,000	30,000	36,000	42,000	48,000	54,000	60,000
50	7	7.14	1,400	7,000	14,000	21,000	28,000	35,000	42,000	49,000	56,000	63,000	70,000
50	8	6.25	1,600	8,000	16,000	24,000	32,000	40,000	48,000	56,000	64,000	72,000	80,000
50	9	5.55	1,800	9,000	18,000	27,000	36,000	45,000	54,000	63,000	72,000	81,000	90,000
50	10	5.00	2,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000
50	11	4.54	2,200	11,000	22,000	33,000	44,000	55,000	66,000	77,000	88,000	99,000	110,000
50	12	4.16	2,400	12,000	24,000	36,000	48,000	60,000	72,000	84,000	96,000	108,000	120,000
50	13	3.846	2,600	13,000	26,000	39,000	52,000	65,000	78,000	91,000	104,000	117,000	130,000
50	14	3.57	2,800	14,000	28,000	42,000	56,000	70,000	84,000	98,000	112,000	126,000	140,000
60	6	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
60	7	8.57	1,167	5,835	11,670	17,505	23,340	29,175	35,010	40,845	46,680	52,515	58,350
60	8	7.50	1,333	6,665	13,330	19,995	26,660	33,325	39,990	46,665	53,320	59,985	66,650
60	9	6.66	1,500	7,500	15,000	22,500	30,000	37,500	45,000	52,500	60,000	67,500	75,000
60	10	6.00	1,667	8,335	16,670	25,005	33,340	41,675	50,010	58,345	66,680	75,015	83,350
60	11	5.45	1,833	9,165	18,333	27,495	36,660	45,825	54,990	64,155	73,320	82,485	91,650
60	12	5.00	2,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000
60	13	4.615	2,167	10,835	21,670	32,505	43,340	54,175	65,010	75,845	86,680	97,515	108,350
60	14	4.28	2,333	11,665	23,330	34,995	46,660	58,325	69,990	81,665	93,320	104,985	116,650
70	6	11.66	857	4,285	8,570	12,855	17,140	21,425	25,710	29,995	34,280	38,565	42,850
70	7	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
70	8	8.75	1,143	5,715	11,430	17,145	22,860	28,575	34,290	40,005	45,720	51,435	57,150
70	9	7.77	1,286	6,430	12,860	19,290	25,720	32,150	38,580	45,010	51,440	57,870	64,300
70	10	7.00	1,429	7,145	14,290	21,435	28,580	35,725	42,870	50,015	57,160	64,305	71,450
70	11	6.36	1,571	7,855	15,710	23,565	31,420	39,275	47,130	54,985	62,840	70,695	78,550
70	12	5.83	1,714	8,570	17,140	25,710	34,280	42,850	51,420	59,990	68,560	77,130	85,700
70	13	5.38	1,857	9,285	18,570	27,855	37,140	46,425	55,710	64,995	74,280	83,565	92,850
70	14	5.00	2,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000

TC/A	Q. R.	TS/A	Ac's Per 10,000 TS	Total Man-Days At 5 M/A	10 M/A	15 M/A	20 M/A	25 M/A	30 M/A	35 M/A	40 M/A	45 M/A	50 M/A
80	6	13.33	750	3,750	7,500	11,250	15,000	18,750	22,500	26,250	30,000	33,750	37,500
80	7	11.428	875	4,375	8,750	13,125	17,500	21,875	26,250	30,625	35,000	39,375	43,750
80	8	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
80	9	8.888	1,125	5,625	11,250	16,875	22,500	28,125	33,750	39,375	45,000	50,625	56,250
80	10	8.00	1,250	6,250	12,500	18,750	25,000	31,250	37,500	43,750	50,000	56,250	62,500
80	11	7.27	1,375	6,875	13,750	20,625	27,500	34,375	41,250	48,125	55,000	61,875	68,750
80	12	6.66	1,500	7,500	15,000	22,500	30,000	37,500	45,000	52,500	60,000	67,500	75,000
80	13	6.15	1,625	8,125	16,250	24,375	32,500	40,625	48,750	56,875	65,000	73,125	81,250
80	14	5.71	1,750	8,750	17,500	26,250	35,000	43,750	52,500	61,250	70,000	78,750	87,500
90	6	15.00	667	3,335	6,670	10,005	13,340	16,675	20,010	23,345	26,680	30,015	33,350
90	7	12.85	778	3,890	7,780	11,670	15,560	19,450	23,340	27,230	31,120	35,010	38,900
90	8	11.25	889	4,445	8,890	13,335	17,780	22,225	26,670	31,115	35,560	40,005	44,450
90	9	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
90	10	9.00	1,111	5,555	11,110	16,665	22,220	27,775	33,330	38,885	44,440	49,995	55,550
90	11	8.18	1,222	6,110	12,220	18,330	24,440	30,550	36,660	42,770	48,880	54,990	61,100
90	12	7.50	1,333	6,665	13,330	19,995	26,660	33,325	39,990	46,665	53,320	59,985	66,650
90	13	6.92	1,444	7,220	14,440	21,660	28,880	36,100	43,320	50,540	57,760	64,980	72,200
90	14	6.428	1,555	7,775	15,550	23,325	31,100	38,875	46,650	54,425	62,200	69,975	77,750
100	6	16.66	600	3,000	6,000	9,000	12,000	15,000	18,000	21,000	24,000	27,000	30,000
100	7	14.285	700	3,500	7,000	10,500	14,000	17,500	21,000	24,500	28,000	31,500	35,000
100	8	12.50	800	4,000	8,000	12,000	16,000	20,000	24,000	28,000	32,000	36,000	40,000
100	9	11.11	900	4,500	9,000	13,500	18,000	22,500	27,000	31,500	36,000	40,500	45,000
100	10	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
100	11	9.09	1,100	5,500	11,000	16,500	22,000	27,500	33,000	38,500	44,000	49,500	55,000
100	12	8.33	1,200	6,000	12,000	18,000	24,000	30,000	36,000	42,000	48,000	54,000	60,000
100	13	7.69	1,300	6.500	13,000	19,500	26,000	32,500	39,000	45,500	52,000	58,500	65,000
100	14	7.14	1,400	7,000	14,000	21,000	28,000	35,000	42,000	49,000	56,000	63,000	70,000

Operations to include: Replanting, palipaliing, weeding, spraying, cultivating, and applying fertilizer, but not cost of fertilizer.
Rate of pay in this paper considered at $1.50 per man-day.

TABLE II

MAN-DAY REQUIREMENTS FOR HARVESTING 10,0000 TONS OF SUGAR
(Cutting and Loading Only)

					50 TC/A			60 TC/A			70 TC/A			80 TC/A			90 TC/A			100 TC/A		
TC/M	Q. R.	TS/M	Men Per 10,000 TS	TC Per 10,000 TS	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A
3	6	.5000	20,000	60,000	1,200	16.6	8.33	1,000	20	10.00	857	23.3	11.66	750	26.6	13.33	667	30	15.00	600	33.3	16.66
3	7	.42857	23,333	70,000	1,400	16.6	7.14	1,167	20	8.57	1,000	23.3	10.00	875	26.6	11.428	778	30	12.857	700	33.3	14.285
3	8	.3750	26,666	80,000	1,600	16.6	6.25	1,333	20	7.50	1,143	23.3	8.75	1,000	26.6	10.00	889	30	11.25	800	33.3	12.50
3	9	.3333	30,000	90,000	1,800	16.6	5.55	1,500	20	6.66	1,286	23.3	7.77	1,125	26.6	8.888	1,000	30	10.00	900	33.3	11.11
3	10	.3000	33,333	100,000	2,000	16.6	5.00	1,667	20	6.00	1,429	23.3	7.00	1,250	26.6	8.00	1,111	30	9.00	1,000	33.3	10.00
3	11	.2727	36,666	110,000	2,200	16.6	4.54	1,833	20	5.45	1,571	23.3	6.36	1,375	26.6	7.27	1,222	30	8.18	1,100	33.3	9.09
3	12	.2500	40,000	120,000	2,400	16.6	4.16	2,000	20	5.00	1,714	23.3	5.83	1,500	26.6	6.66	1,333	30	7.50	1,200	33.3	8.33
3	13	.23077	43,333	130,000	2,600	16.6	3.846	2,167	20	4.615	1,857	23.3	5.38	1,625	26.6	6.15	1,444	30	6.92	1,300	33.3	7.69
3	14	.21428	46,666	140,000	2,800	16.6	3.57	2,333	20	4.28	2,000	23.3	5.00	1,750	26.6	5.71	1,555	30	6.428	1,400	33.3	7.14
3.5	6	.5833	17,144	60,000	1,200	14.3	8.33	1,000	17.1	10.00	857	20	11.66	750	22.8	13.33	667	25.7	15.00	600	28.6	16.66
3.5	7	.5000	20,000	70,000	1,400	14.3	7.14	1,167	17.1	8.57	1,000	20	10.00	875	22.8	11.428	778	25.7	12.857	700	28.6	14.285
3.5	8	.4375	22,857	80,000	1,600	14.3	6.25	1,333	17.1	7.50	1,143	20	8.75	1,000	22.8	10.00	889	25.7	11.25	800	28.6	12.50
3.5	9	.38889	25,713	90,000	1,800	14.3	5.55	1,500	17.1	6.66	1,286	20	7.77	1,125	22.8	8.888	1,000	25.7	10.00	900	28.6	11.11
3.5	10	.3500	28,571	100,000	2,000	14.3	5.00	1,667	17.1	6.00	1,429	20	7.00	1,250	22.8	8.00	1,111	25.7	9.00	1,000	28.6	10.00
3.5	11	.31818	31,429	110,000	2,200	14.3	4.54	1,833	17.1	5.45	1,571	20	6.36	1,375	22.8	7.27	1,222	25.7	8.18	1,100	28.6	9.09
3.5	12	.29166	34,286	120,000	2,400	14.3	4.16	2,000	17.1	5.00	1,714	20	5.83	1,500	22.8	6.66	1,333	25.7	7.50	1,200	28.6	8.33
3.5	13	.2692	37,147	130,000	2,600	14.3	3.846	2,167	17.1	4.615	1,857	20	5.38	1,625	22.8	6.15	1,444	25.7	6.92	1,300	28.6	7.69
3.5	14	.2500	40,000	140,000	2,800	14.3	3.57	2,333	17.1	4.28	2,000	20	5.00	1,750	22.8	5.71	1,555	25.7	6.428	1,400	28.6	7.14
4	6	.6666	15,000	60,000	1,200	12.5	8.33	1,000	15	10.00	857	17.5	11.66	750	20	13.33	667	22.5	15.00	600	25	16.66
4	7	.5714	17,500	70,000	1,400	12.5	7.14	1,167	15	8.57	1,000	17.5	10.00	875	20	11.428	778	22.5	12.857	700	25	14.285
4	8	.5000	20,000	80,000	1,600	12.5	6.25	1,333	15	7.50	1,143	17.5	8.75	1,000	20	10.00	889	22.5	11.25	800	25	12.50
4	9	.4444	22,500	90,000	1,800	12.5	5.55	1,500	15	6.66	1,286	17.5	7.77	1,125	20	8.888	1,000	22.5	10.00	900	25	11.11
4	10	.4000	25,000	100,000	2,000	12.5	5.00	1,667	15	6.00	1,429	17.5	7.00	1,250	20	8.00	1,111	22.5	9.00	1,000	25	10.00
4	11	.3636	27,500	110,000	2,200	12.5	4.54	1,833	15	5.45	1,571	17.5	6.36	1,375	20	7.27	1,222	22.5	8.18	1,100	25	9.09
4	12	.3333	30,000	120,000	2,400	12.5	4.16	2,000	15	5.00	1,714	17.5	5.83	1,500	20	6.66	1,333	22.5	7.50	1,200	25	8.33
4	13	.30769	32,500	130,000	2,600	12.5	3.846	2,167	15	4.615	1,857	17.5	5.38	1,625	20	6.15	1,444	22.5	6.92	1,300	25	7.69
4	14	.2857	35,000	140,000	2,800	12.5	3.57	2,333	15	4.28	2,000	17.5	5.00	1,750	20	5.71	1,555	22.5	6.428	1,400	25	7.14
5	6	.8333	12,000	60,000	1,200	10	8.33	1,000	12	10.00	857	14	11.66	750	16	13.33	667	18	15.00	600	20	16.66
5	7	.71428	14,000	70,000	1,400	10	7.14	1,167	12	8.57	1,000	14	10.00	875	16	11.428	778	18	12.857	700	20	14.285
5	8	.6250	16,000	80,000	1,600	10	6.25	1,333	12	7.50	1,143	14	8.75	1,000	16	10.00	889	18	11.25	800	20	12.50
5	9	.5555	18,000	90,000	1,800	10	5.55	1,500	12	6.66	1,286	14	7.77	1,125	16	8.888	1,000	18	10.00	900	20	11.11
5	10	.5000	20,000	100,000	2,000	10	5.00	1,667	12	6.00	1,429	14	7.00	1,250	16	8.00	1,111	18	9.00	1,000	20	10.00
5	11	.45454	22,000	110,000	2,200	10	4.54	1,833	12	5.45	1,571	14	6.36	1,375	16	7.27	1,222	18	8.18	1,100	20	9.09
5	12	.41666	24,000	120,000	2,400	10	4.16	2,000	12	5.00	1,714	14	5.83	1,500	16	6.66	1,333	18	7.50	1,200	20	8.33
5	13	.3846	26,000	130,000	2,600	10	3.846	2,167	12	4.615	1,857	14	5.38	1,625	16	6.15	1,444	18	6.92	1,300	20	7.69
5	14	.3571	28,000	140,000	2,800	10	3.57	2,333	12	4.28	2,000	14	5.00	1,750	16	5.71	1,555	18	6.428	1,400	20	7.14

Symbols:

TC/M = Tons net cane per man cut and load or cut and pack.
Q. R. = Quality ratio.
TS/M = Tons sugar per man cut and load or cut and pack.
Ac's = Acres.
M/A = Men per acre.
TS = Tons sugar.
TS/A = Tons sugar per acre.
TC/A = Tons cane per acre.

$$\text{TS/M} = \frac{\text{TC/M}}{\text{Q. R.}}$$

$$\text{Men per 10,000 TS} = \frac{\text{10,000 TS}}{\text{TS/M}}$$

$$\text{Ac's per 10,000 TS} = \frac{\text{10,000 TS}}{\text{TS/A}}$$

TC/M—Example: 1 man cuts 7.5 tons net cane
1 man loads 15 tons net cane
or 2 men cut 15 tons net cane
1 man loads 15 tons net cane

3 men cut and load 15 tons net cane
or 1 man cuts and loads 5 tons net cane

TABLE III

DELIVERY COSTS PER TON NET CANE AND DELIVERY COSTS PER 10,000 TONS OF SUGAR

Q. R.	TC Per 10,000 TS	$ .80	$ .90	$1.00	$1.10	$1.20	$1.30	$1.40	$1.50	$1.60	$1.70
6	60,000	$ 48,000	$ 54,000	$ 60,000	$ 66,000	$ 72,000	$ 78,000	$ 84,000	$ 90,000	$ 96,000	$102,000
7	70,000	56,000	63,000	70,000	77,000	84,000	91,000	98,000	105,000	112,000	119,000
8	80,000	64,000	72,000	80,000	88,000	96,000	104,000	112,000	120,000	128,000	136,000
9	90,000	72,000	81,000	90,000	99,000	108,000	117,000	126,000	135,000	144,000	153,000
10	100,000	80,000	90,000	100,000	110,000	120,000	130,000	140,000	150,000	160,000	170,000
11	110,000	88,000	99,000	110,000	121,000	132,000	143,000	154,000	165,000	176,000	187,000
12	120,000	96,000	108,000	120,000	132,000	144,000	156,000	168,000	180,000	192,000	204,000
13	130,000	104,000	117,000	130,000	143,000	156,000	169,000	182,000	195,000	208,000	221,000
14	140,000	112,000	126,000	140,000	154,000	168,000	182,000	196,000	210,000	224,000	238,000

Note: Delivery costs to include such operations as cutting and loading or cutting and packing, installing portable tracks or flumes, etc., as well as transportation.

TABLE IV

MANUFACTURING COSTS PER TON OF SUGAR AND MANUFACTURING COSTS PER 10,000 TONS OF SUGAR

	8 Per Cent Trash		10 Per Cent Trash		12 Per Cent Trash		14 Per Cent Trash		16 Per Cent Trash		18 Per Cent Trash	
Q. R.	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS
6	$1.10	$11,000	$1.12	$11,200	$1.14	$11,400	$1.17	$11,700	$1.19	$11,900	$1.21	$12,100
7	1.28	12,800	1.31	13,100	1.33	13,300	1.36	13,600	1.39	13,900	1.41	14,100
8	1.46	14,600	1.49	14,900	1.53	15,300	1.55	15,500	1.58	15,800	1.61	16,100
9	1.65	16,500	1.68	16,800	1.72	17,200	1.75	17,500	1.78	17,800	1.81	18,100
10	1.83	18,300	1.87	18,700	1.91	19,100	1.95	19,500	1.98	19,800	2.02	20,200
11	2.03	20,300	2.06	20,600	2.10	21,000	2.14	21,400	2.18	21,800	2.22	22,200
12	2.20	22,000	2.24	22,400	2.29	22,900	2.33	23,300	2.38	23,800	2.42	24,200
13	2.38	23,800	2.43	24,300	2.48	24,800	2.53	25,300	2.57	25,700	2.62	26,200
14	2.57	25,700	2.62	26,200	2.67	26,700	2.72	27,200	2.77	27,700	2.82	28,200

Above data obtained as follows:

Factory handles 90 tons of net cane per hour or 97.82 tons of gross cane per hour with 8 per cent trash.

24 hours × 90 = 2,160 net tons cane per day.
Q. R. 10 = 216 tons of sugar per day.
Q. R. 12 = 180 tons of sugar per day.

Assume operating costs of factory = $396 per day.

$\frac{\$396}{216\ \text{TS}}$ = $1.83 per ton of sugar with Q. R. 10. Tare 8 per cent.

$\frac{\$396}{180\ \text{TS}}$ = $2.20 per ton of sugar with Q. R. 12. Tare 8 per cent.

If trash is increased 2 per cent,
Then 90 ÷ 102 = 88.2 tons net cane per hour,
or 88.2 × 24 = 2116.8 tons net cane per day.

$\frac{2116.8}{10\ \text{Q.R.}}$ = 211.7 tons of sugar per day.

$\frac{\$396}{211.7\ \text{TS}}$ = $1.87 per ton of sugar Q. R. 10. Tare 10 per cent.

Notes on a New Species of Pyrophorus Introduced Into Hawaii to Combat *Anomala Orientalis* Waterhouse

BY F. A. BIANCHI

Pyrophorus bellamyi Van Zwal., the only known West Coast representative in Guatemala of a genus represented by two or more species in the eastern section of that republic, was introduced into the Hawaiian Islands by Dr. F. X. Williams and the writer during 1934 and 1935. Although neither adults nor larvae have yet been recovered in the field, it is hoped that in Hawaii the predacious larvae of this insect will eventually become an important factor in the control of white grubs, both Anomala and Adoretus, and if this happens the following notes, gathered incidentally in the course of work connected with the introduction, may prove of interest to Hawaiian entomology in general and to the sugar planters in particular.

Shipments and Technique:

Beginning with a first shipment in May 1934 and ending with one in April 1935, a total of 512 Pyrophorus larvae in various late stages of development was sent from Guatemala in five lots. Packed individually in tin pillboxes filled with sterilized soil slightly moistened, 466 out of the 512 larvae arrived in good shape. Most of them had keen kept and fed in the field laboratory for periods of from one day to three weeks and all were fed immediately before shipment, but no food was provided during the voyage. Upon arrival in Honolulu the original pillboxes continued to serve but the Guatemala soil was discarded in favor of soil from Oahu Sugar Company, Ltd., which thenceforth was changed twice a week. The majority of the Pyrophorus larvae was kept in the laboratory until emergence of the adults but 108 larvae were liberated as such, being shallowly buried on October 25, 1935 in the soil of fields 44 and 46 of Oahu Sugar Company. The adults were all liberated in various fields of this plantation, with the exception of one lot which was liberated in the Manoa Valley substation of the H.S.P.A. This lot consisted of nine males and 42 females and included several hundred very young larvae and eggs secured in the laboratory. The last liberation recorded took place on April 24, 1936 in field 55 of Oahu Sugar Company. It consisted of three males and four females reared from eggs laid in the laboratory in Honolulu.

Habits and Distribution of the Insect in the Field:

As R. H. Van Zwaluwenburg has recorded (*Proceedings of the Hawaiian Entomological Society,* 9:231-234, 1936), the adults of Pyrophorus are evidently of very secretive habits. To our knowledge only one has ever been seen in the field. This one was found by Dr. Williams early in the morning of June 16, 1934 on the foliage of a glandular compositae allied to Helianthus. In contrast to what might prove to be the case with *Pyrophorus radians* and other members of the genus, which in eastern Guatemala and elsewhere are easily found and often collected, the secretiveness of

bellamyi will probably be of advantage to it in the struggle to become established in Hawaii. In spite of its noctuŕnal habits it is not likely to become the prey of *Bufo marinus.*

So far *P. bellamyi* has been reported from within the confines of one plantation only—"El Salto"—a sugar cane plantation not far from the town of Escuintla, Guatemala. In this plantation the larvae, first observed by the writer early in 1933, were not evenly distributed, the great majority of those obtained for shipment to Honolulu having been found in one sporadically cultivated field some forty acres in extent near the plantation headquarters. This field was given to *Panicum maximum* during our stay in Guatemala and the soil was of soft texture and usually moderately moist; but several full-grown larvae were from time to time found in other fields where the soil was drier and harder. In the areas of abundance the larvae were found from one to sixteen inches below the surface of the ground; the majority in the neighborhood of six or eight inches. It is probable that at least in the later instars they depended for food mainly on the larvae of scarabs, the vertical range of dispersion of which roughly coincided with that of Pyrophorus.

It was obvious that the larvae covered considerable distances through the soil in search of food, and there was some indication that collective vertical migrations took place which may have been of seasonal occurrence.

In the few instances when pupae were dug up in the field they were invariably in the harder layer below the surface soil and rested, on their back in every case, within cells that seemed to have been made by repeated pushing of the pre-pupae against the soil immediately surrounding them. The cells were somewhat larger than their inmates permitting these to roll over without difficulty when disturbed.

No indication was found of any larval parasite of *bellamyi*, but in view of the enormous fertility of the female the relative scarcity of all stages of the insect in the field points to the existence of powerful inimical factors in its environment.

Adults kept in large jars in the laboratory were supplied with pieces of split sugar cane or with leaves smeared with honey. They seemed to take advantage of the food thus provided only very rarely, but one newly emerged female was seen actually feeding on the drops of honey. They were very sluggish under any conditions and spent most of the time resting on the pieces of cane or on the surface of the soil in the bottom of the jars, occasionally burying themselves just under the surface soil. On being picked up by hand they often, but not always, "played possum." We have never seen them in flight either in the laboratory or in the field; nor have they been observed mating or displaying the slightest interest in the opposite sex.

Brief Description of the Beetle:

Pyrophorus bellamyi was described as a new species by Van Zwaluwenburg. As the accompanying illustration shows (Fig. 1A), it is an insect generally resembling *Conoderus exul,* the well known click beetle of our cane fields, but it can be easily distinguished even by the layman from Conoderus by its much greater size and by its ability to emit a beautiful greenish phosphorescence which is easily visible even in daylight. While in the larva no exterior anatomical detail indicates this ability, in the adult two luminous organs are well defined as large, sub-oval, grayish

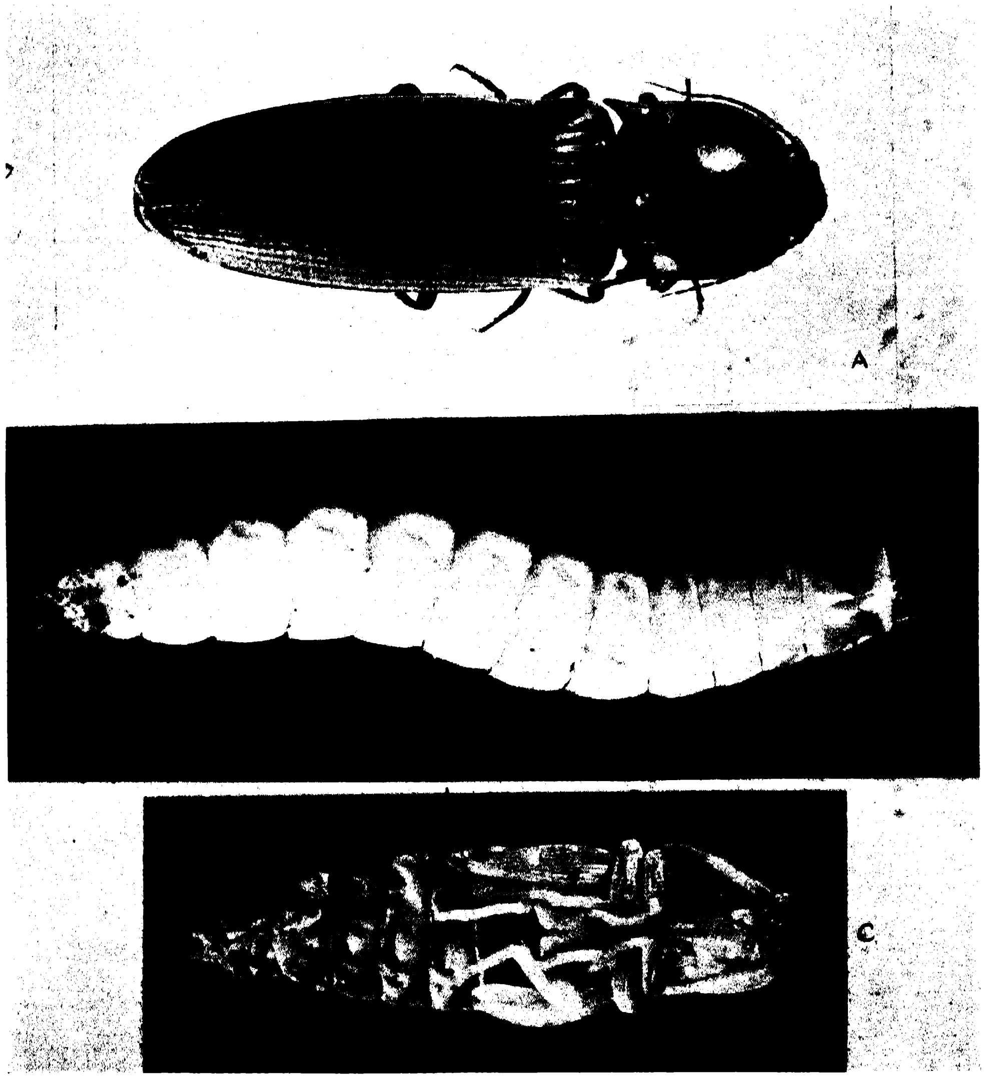

Fig. 1. *A*. Female beetle of Pyrophorus. Notice the gray areas near the hind angles of the prothorax; these are the luminous eye spots of the living insect. *B*. Full-grown larva of Pyrophorus. *C*. Pupa of Pyrophorus.

areas visible through the dorsal and the ventral cuticle covering of the posterior angles of the pronotum.

Differences between the sexes in the adult stage of Pyrophorus are perceptible only to the very careful observer, one of the most obvious being that in the female the prothorax is more convex and more robust in relation to the elytra than is the case with the male. In general, females can be distinguished by their greater length and girth, particularly when carrying a full complement of eggs; but, as the following measurements show, some overlapping occurs and size is not always a reliable criterion.

SIZE OF FEMALES

No. of item	Length from tip of mandibles to tip of abdomen in millimeters	Width of the base of the elytra in millimeters
1	35	9
2	33.5	9
3	32	9
4	31	8
5	31	8.5
6	31	8
7	31	8.5
8	31	8
9	30	7.5
10	30	8
11	29.5	7.5
12	29.5	7.5
13	29.5	7.5
14	28	7.5
15	28	7
16	25	6.5
17	25	6.5
18	21	5.5

SIZE OF MALES

1	24	6
2	24	6
3	23.5	6
4	20.5	5.5
5	20.5	5.5
6	19.5	5

Brief Description of the Larvae:

The larvae of Pyrophorus are active, elongate, cylindrically segmented insects not easily distinguishable by the layman from other wireworms of our fields. Pale white entirely, except for slight chitinization of the mouth parts and certain portions of the terminal abdominal segment, the first instar is very minute and inconspicuous and is hardly likely to be seen outside of the laboratory. Five mounted specimens measured micrometrically 2.5, 2.6, 2.7, 2.25, and 2.55 millimeters in length respectively. The second instar may or may not have perceptibly increased in size; it shows but slight enlargement and intensification of the chitinous areas and can best be distinguished from the first instar by the changes which appear in the ninth abdominal segment, which our illustrations show (Fig. 2A and B). In the third, or possibly in the fourth instar—an uncertain point—the larva becomes more heavily chitinized in the head and distal regions, and in all but its smaller size and paler coloring assumes the appearance of the full-grown wireworm.

The fully developed larva is illustrated in Fig. 1B. The insect in this stage is comparable in size only to the larva of *Chalcolepedius erythroloma* among the Elaterids found in Hawaii. The head and mouth parts; certain tubercules of the ninth and tenth abdominal segments; parts of the legs; and the dorsal sclerite of the first body segment are heavily chitinized. The cuticle is everywhere tough, almost leathery, yellowish in color, and the whole insect is a vigorous, very hardy individ-

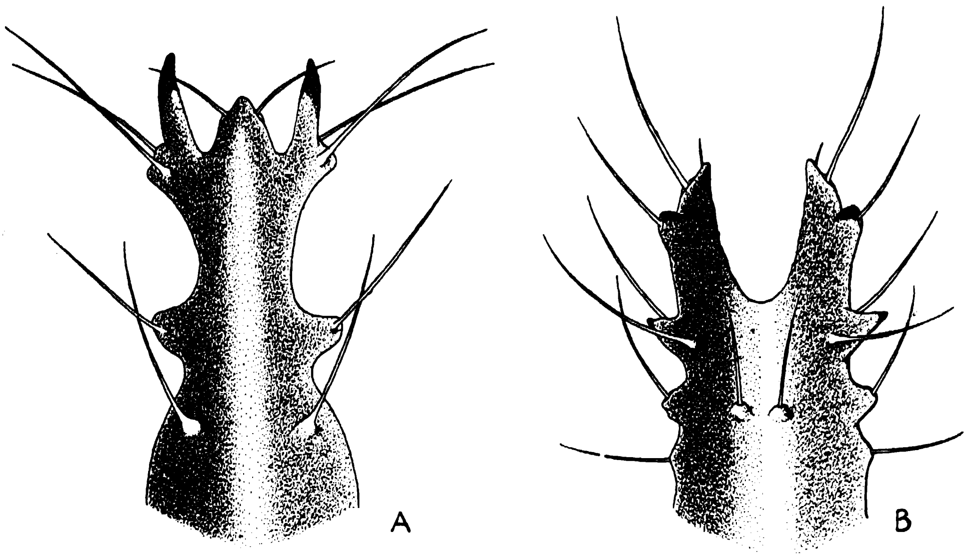

Fig. 2. *A* and *B*. Dorsal appearance of the ninth abdominal segment in first and second instars of *Pyrophorus bellamyi*.

ual capable of withstanding much rough handling, prolonged periods of starvation, and a wide range of temperature and moisture conditions. One larva showed no ill effects when relieved of a thick accumulation of mites with a brush dipped in carbolic acid.

Rough measurements of the body length of seven individuals measured during the last larval instar were 32, 34, 35, 37, 38, 42, and 50 millimeters respectively. The weight of one of the largest larvae we have observed was 1,450 milligrams.

In contrast to other measurements, the greatest width of the ventral mouth parts showed only occasional variation from the norm among the last larval instars of individuals collected in the field. A series of 13 random measurements made on the last moulted larval skins gave the following results in millimeters: one of 1.980, one of 2.442, seven of 2.640, one of 2.706, two of 2.772, and one of 2.970.

The first case in the list (one of 1.980) proved to be the larva of an undersized male which may not have moulted as many times as the others.

The pupa of Pyrophorus, as can be seen in the accompanying illustration (Fig. 1C), is also very much like the corresponding stage of our other Elaterids. It is more than twice the size, however, of any similar pupa likely to be found in the cane fields.

The Luminescence of Pyrophorus bellamyi:

Because of its greenish quality the luminescense produced by the larvae and adults of Pyrophorus is visible even under fairly strong natural or artificial light. In the adults it is present at all times but the larvae may go long periods without showing it. Whether the ability to produce it ever completely and permanently disappears is not known but it was distinctly observed that field-collected larvae were less apt to glow in the laboratory after a few moults than they had been in the field. It is not recalled, in fact, that any larvae failed to glow when first handled in

the field or that any failed to react in a similar manner for several days later, whenever they were disturbed.

When luminescence is present either in larvae, pupae, or adults it is constant at a certain minimum of intensity. At this minimum it may be hardly perceptible or easily distinguishable but both the intensity of the light and the extent of the luminescent areas increase suddenly when the insect is prodded or shaken. A maximum of intensity is then quickly reached, followed by a more gradual return to the constant minimum. This wave-like increase and decrease of intensity occurs in the pupae, pre-pupae, and adults of Pyrophorus as well as in the larvae and is not confined to any particular luminous area of the body, extending simultaneously, or nearly so, to all of them. It is seemingly a voluntary reaction with a protective purpose and in the case of luminescent larvae it is invariably associated with the act of biting, when the individual is sufficiently aroused to have recourse to this more vigorous defense.

In active larvae the luminescent area includes as a rule only the first segment of the body, the prothorax, which may be luminescent ventrally and dorsally over its whole width or, very often, only over a more or less narrow anterior portion. In striking contrast, during the inactive pre-pupal and pupal stages, and very rarely in the case of active larvae, as well, the light-producing organs seem to become released from their usual anchorage and, being distributed somehow throughout the body, cause luminescent areas to appear on other segments. In some specimens the entire body, including the head, glows beautifully and, as the light appears more brightly in these cases along the transversal sutures of the body, the insect is strikingly outlined in greenish light.

In fully developed adults luminescence is limited to some of the dorsal sutures of the body and to the ventral and dorsal surfaces of the posterior angles of the prothorax, where it appears in the large sub-oval areas mentioned earlier. It has been noted, however, that recently emerged adults, in which chitinization has not taken place, are luminescent throughout the entire body in a manner similar to that of the pupae and pre-pupae.

Luminescence has not been observed by us in either the eggs or the very young larvae of *Pyrophorus bellamyi,* the youngest individual in which luminescence was apparent having already reached the third or fourth instar of its growth. Luminescence was limited in this case to the first segment of the body and its intensity increased in response to stimuli in the wave-like manner discussed above but the waves were of distinctly shorter duration than in the case of larger larvae.

In two out of four larvae in which luminescence had not been apparent for many weeks it appeared suddenly and fairly strong when the larvae were plunged into cold water. As no luminescence had previously been obtained from any of these four larvae, even by vigorous shaking and prodding, this observation perhaps explains why women and children in Mexico used to "bathe" the "cucuyos," a species of Pyrophorus closely related to *bellamyi,* which during Colonial days were worn as adornments in little gauze bags pinned to the hair. (Insect lore of the Aztecs, C. H. Curran, *Natural History,* 39: 196-203, 1937). Our observation, however, was made on the larvae of Pyrophorus and we have had no opportunity to ascertain whether it also applies to the adults.

Cases of Prothetely:

Prothetely is the term applied to the abnormal condition of larvae showing precocious development of pupal or imaginal characters.

As has been observed to be the case with other insects, the incidence of this condition among larvae of *Pyrophorus bellamyi* seems to increase greatly under laboratory conditions. Out of nearly 600 larvae collected in El Salto not a single prothetelous example was found, but at least four larvae developed prothetely after being kept in the laboratory for a time. Three of these died before reaching the pupal stage, but one underwent two larval moults and pupated, eventually emerging as a perfectly normal female. The laboratory record of this individual is as follows:

March 29, 1933: A larva about half-grown found under cane trash in El Salto. Fed one or two grubs per diem until May 18. Was not fed at all between May 18 and June 23. Resumed usual rate of feeding on June 23, and between this date and the date of pupation consumed 53 large or medium sized grubs and two Scarab pupae.

July 10, 1933: Shed normal skin and new instar appeared with two wing pads on each side of the thorax. The pads appear to be pointed, egg-shaped evaginations of the body wall filled either with body juices or air. They can be pinched or pressed out of shape to some extent but quickly regain their former outline when the pressure is removed. They are considerably constricted at the point of attachment to the body. The posterior one folds closely against the body and the anterior one folds closely over the posterior one. They are not very different in size and measure about 3.5 millimeters in length by 2 millimeters at the point of greatest width.

November 22, 1933: Shed again without difficulty and wing pads appeared considerably reduced in size and altered in shape. They are now lightly chitinized tubercules somewhat constricted at the base.

December 28, 1933: Moulted again. Mesothoracic pads disappeared completely but prothoracic pads remained unaltered in shape and only slightly reduced in size.

April 9, 1934: Transformed into a perfect pupa after a short and not clearly defined pre-pupal rest period.

April 17, 1934: Normal, fair-sized adult female emerged.

June 20, 1934: Adult died.

Unfortunately the series of photographs presented herewith (Figs. 3 A, B, and C) is not of the larva which successfully reached the adult stage but of one of the other three which died in the attempt. The photographs give a very good idea, nevertheless, of the general appearance of the wing pads in all our four cases of prothetely and of the changes they underwent in successive moults in the three cases where the larvae died.

Measurements of the mouth parts of two of the larvae which died before pupating showed they had probably reached full larval growth at the time of their death. The mouth parts of the last two successive moults, in the case of one of these larvae, both measured 2.60 millimeters in width, showing that no body growth had taken place during the last two prothetelous instars. The death of all three larvae occurred during the process of moulting or shortly after an incomplete moult.

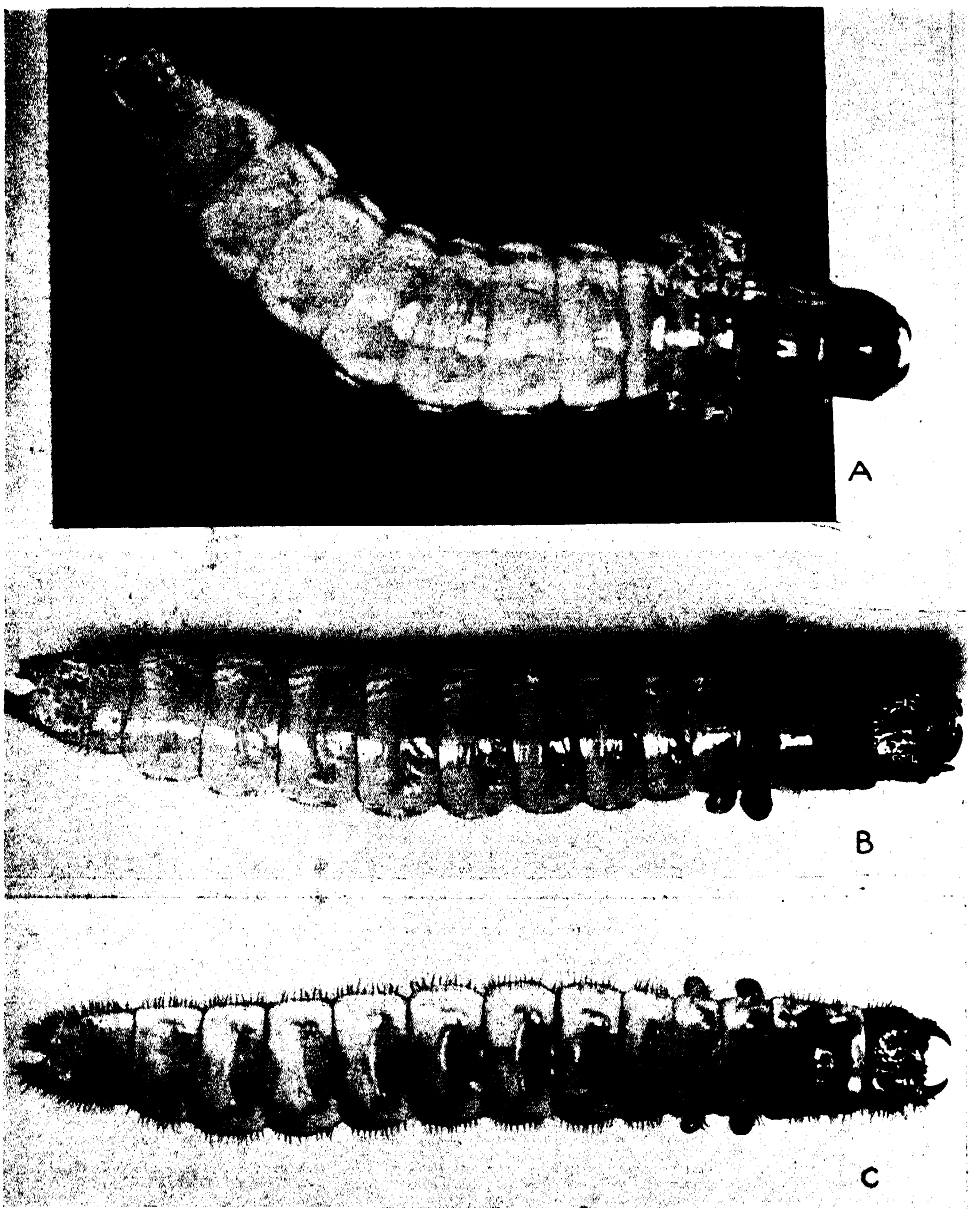

Fig. 3. *A, B,* and *C.* Showing the gradual reduction of the wing pads in three successive instars of a prothetelous larva of *Pyrophorus bellamyi.* This larva died in the condition shown in *C.*

Life History

Oviposition:

Females kept in large jars partly filled with loose soil did not group their eggs in any particular manner but distributed them unevenly throughout the soil.

Records of oviposition were obtained in Honolulu from two females emerged from larvae collected in the field at El Salto. Both of these were placed with a male within a day of their emergence. The first produced two batches of eggs; one batch of approximately 300 eggs was laid 35 days after the emergence of the mother; the

second batch, 385 eggs, was laid 20 days later, or 55 days after the emergence of the mother and only two days before her death. No count was made of any eggs which may have remained within this female after death. The second female also laid her eggs in two batches, both of 91 eggs; the first batch laid 43 days and the second batch 64 days after emergence of the mother and shortly before her death. This female still retained 1,292 fully formed eggs within her body after death, so that her total potential production amounted to 1,474 eggs. A third female, dissected before oviposition had taken place, yielded a total of 4,425 eggs.

As oviposition was not timed in any case, the period of incubation was not ascertained, but it appears to be shorter than the 10 to 16 days which Wolcott gives for the related *Pyrophorus luminosus* Illiger. (El Cucubano, Circular No. 80, Departmento de Agricultura y Trabajo, Gobierno de Puerto Rico, 1923.)

The Eggs:

The eggs of *Pyrophorus bellamyi* are spherical, milk-white, slightly shiny, and so smooth that they show no sculpturing even under high magnification. Micrometrical measurements of 11 eggs dissected from a gravid female preserved in alcohol showed two with a diameter of .50 millimeter, two with .48 millimeter, four with .46 millimeter, and three with .44 millimeter, giving an average diameter of .465 millimeter for the lot.

In the laboratory, close observation has not revealed to the writer at any time the luminescence in the eggs of *P. bellamyi* which is said to be apparent in the eggs of related species. Possibly it occurs under hitherto undetermined conditions.

Number of Instars:

As is known to be the case with most insects, the gross size of Pyrophorus larvae does not provide an accurate criterion of their age or the number of moults which they may have undergone. A satisfactory criterion is provided by the size of the head capsule, which according to Dyar's Law (The Number of Molts of Lepidopterous larvae, H. G. Dyar, *Psyche*, 5: 420-422, 1890) follows regular geometric progression in successive instars. This does not mean, of course, that the head capsules of all the individuals of a certain instar will be of exactly the same size but that their measurements will fall between two well-defined limits of a mathematical interval. Our data are insufficient to permit definition of these intervals in the case of Pyrophorus but provide an approximate indication of what they may be for certain instars, as is shown in Table I.

TABLE I

Showing the greatest width in millimeters of ventral mouth parts shed by Pyrophorus larvae during successive moults preceding pupation. "P" indicates the point at which pupation occurred. It is not known in the case of any of the larvae here tabulated how many moults may have preceded those whose measurements are given.

Lab. No. of Specimen	Greatest Width in Millimeters								
A1	..	.86	1.02	1.28	1.60	P			
A2	.66	.80	1.00	1.30	1.56	P			
A3	.62	.80	1.10	1.50	1.64	P			
A4	.70	.90	1.10	1.40	1.60	P			
A5	..	.84	1.18	1.46	1.60	1.75	2.00	2.05	P
A6	..	.84	1.08	1.44	1.60	P			
A7	..	..	1.02	1.28	1.46	P			
A8	..	.68	.88	1.20	1.60	1.85	P		

This table, following McDougall's rather than Dyar's example, gives the greatest width of the ventral mouth parts, rather than the greatest width of the whole head capsule. For various reasons (The Determination of Larval Instars and Stadia of Some Wireworms—Elateridae, W. A. McDougall, *Queensland Agricultural Journal* 42: 43-47, 1934) this is an easier measure to obtain and probably a more accurate one. The mouth parts were measured on each exuvia after ecdysis and measurements were made by means of a simple micrometer eyepiece and objectives of powers suited to the various sizes found.

No complete series of measurements was obtained for any one individual and it has not been ascertained beyond question how many times the larvae of *P. bellamyi* moult as a rule before pupation. Our data indicate that probably seven larval ecdysis are undergone in the majority of cases but that sometimes more and sometimes less than this number of moults occur. In Table I the two series of items, A5 and A8, which extend to the right beyond the rest of the items were so placed arbitrarily and are presumed to represent two larvae which lived longer and underwent, respectively, one and two moults more than the others show in the table. This presumption is justified by the fact that the items of series A5 and A8 agree more closely with the other items of the table when so arranged.

Measurements of the ventral mouth parts of a series of sixteen first instars showed widths of .165 millimeter in seven cases and of .132 millimeter in nine cases. The measurements of 16 second instars were all .264 millimeter.

Deviations from Dyar's Law:

Although Dyar's Law evidently applies to Pyrophorus generally enough to retain its validity and usefulness, deviations from the law have been noticed. In the case of three larvae which have been under observation in the laboratory for a long time but whose record is not given in Table I, it has been found that the last two, and in one case the last three, successive mouth-part measurements have not perceptibly varied. Cessation of growth is undoubtedly indicated, but it has not been determined whether growth has ceased permanently or temporarily for the larvae in question are still alive and may moult again before pupation.

Duration of Larval Life:

Lacking field data altogether we judge from laboratory records that the total length of larval life of Pyrophorus is subject to great variation. Table II indicates a very wide range for the duration of every stadium and in regard to the total duration of larval life shows about an equal division between larval lives of approximately one year and those which extend to nearly two years; but one larva not included in the table, hatched from an egg laid in the laboratory on June 1, 1934, has moulted at least six times, and still seems as far as ever from pupation after three years of observation.

That in nature two rather than one year may be the general duration of larval life is indicated by the fact that the majority of the larvae collected in El Salto did not pupate until approximately one year later, although all of them were already large-sized larvae when collected, and although all of them were probably fed more regularly and abundantly after being captured than they could have fed themselves

TABLE II

The dates in the columns numbered from I to VI refer to successive larval moults; the numbers between the dates give the duration in days of the corresponding stadia.

Lab. No. of Specimen	VI		V		IV		III		II		I		Date of Pupation	Duration in days of the pupal period	Date of emergence of adult
B1	5/20/35	23	6/13/35	63	8/15/35	63	10/17/35	24	12/10/35	51	1/30/36	73	4/11/36	..	......
B2	......	..	5/20/35	60	7/19/35	84	10/10/35	47	11/26/35	24	12/20/35	108	4/ 6/36	15	4/21/36
B3	......	..	......	..	......	..	5/ 2/35	22	5/24/35	92	8/24/35	228	4/ 8/36	16	4/24/36
B4	......	..	......	..	......	..	5/ 6/35	135	9/28/35	179	3/25/36	17	4/11/36	..	......
B5	......	..	5/ 7/35	27	6/ 3/35	70	8/22/35	56	10/17/35	101	1/30/36	64	4/ 2/36	..	......
B6	......	..	6/17/35	79	8/24/35	33	9/16/35	21	10/ 7/35	27	12/ 3/35	127	5/ 8/36	18	5/26/36
B7	6/20/35	38	7/20/35	31	8/20/35	37	9/26/35	62	11/26/35	50	1/14/36	62	3/16/36	16	4/ 1/36
B8	......	..	......	..	7/15/35	40	8/24/35	37	9/30/35	51	11/19/35	139	4/ 6/36	13	4/19/36
B9	6/17/35	64	8/20/35	20	9/ 9/35	22	9/30/35	25	10/24/35	48	12/11/35	100	4/20/36	17	4/ 6/36
B10	......	..	9/ 4/35	15	9/19/35	18	10/ 7/35	55	12/11/35	45	1/25/36	161	7/ 4/36	17	7/21/36
B11	......	..	8/10/35	20	8/30/35	27	9/26/35	76	12/11/35	35	1/25/36	51	3/16/36	16	4/ 1/36
B12	......	..	8/10/35	30	9/ 9/35	22	10/ 1/35	64	12/ 3/35	64	2/ 5/36	61	4/ 6/36	13	4/19/36

in the fields. The fact that many field-collected specimens continued to grow in the insectary, some moulting as many as five or six times therein, precludes the supposition that the long life of the larvae in the laboratory might be due to unusual protraction of the last stadium in consequence of unnatural conditions.

Because the duration of the third stadium has not been recorded, and that of the first and second stadia only in a few cases which do not correspond to those recorded in Table II, these stadia are not shown in the table. The first stadium in four cases lasted approximately 17, 17, 22, and 22 days, respectively. The second stadium in two cases lasted 13 and 63 days respectively.

The Pre-Pupal Stage:

Both the duration of the pre-pupal period and the condition of the larva during that stage are apt to vary widely with *Pyrophorus bellamyi.* When the period is short, around six days but sometimes less, it is marked simply by pronounced sluggishness and is not accompanied by any change in the external appearance or behavior of the larva. When the period is long, extending to an observed maximum of 21 days, the larva lies almost invariably on its back; and the legs, completely immobile, are held closely folded against the body. Inactivity is then complete in many cases; but in others the larva, although unable to move its legs, will wriggle vigorously when prodded and will sometimes turn over and over with a curious and characteristic spiral motion which is often accompanied by convulsive movements of the mouth parts and sometimes by the sudden appearance or sudden intensification of light in the luminescent portions of the body.

Duration of the Pupal Stage:

Duration of the pupal stage as recorded under laboratory conditions varies between a maximum of 20 days and a minimum of 12, with a series of 215 observations distributed as follows:

2 cases of 12 days	33 cases of 15 days	24 cases of 18 days
25 " " 13 "	27 " " 16 "	5 " " 19 "
51 " " 14 "	46 " " 17 "	2 " " 20 "

Nearly three-fourths of the items fall in the 14-17 days interval and the average of the series is 16.3 days.

Duration of the Adult Stage:

As will be seen from the following tabulation, our data are insufficient to render a reliable average for the duration of the adult life of *Pyrophorus bellamyi.* Both males and females are evidently apt to range very widely in this respect.

All the figures are from adults emerged in the laboratory from field-collected larvae and kept over soil in jars, without feeding.

Sex	Date of Emergence	Date of Death	No. of Days Lived
Male	3/19/34	5/20/34	63
Male	6/30/35	7/18/35	19
Unrecorded	4/17/34	6/20/34	64
Female	1/10/34	1/30/34	20
Female	4/30/34	5/20/34	21
Female	4/20/34	5/12/34	22
Female	3/22/34	4/18/34	27
Female	4/20/34	5/27/34	37
Female	5/8–11/34	6/23/34	43–46
Female	4/28/34	6/16/34	49
Female	4/18/34	6/21/34	64
Female	3/19/34	6/ 1/34	84

Food Habits of the Larvae:

Pyrophorus larvae are exclusively carnivorous. Confined in jars in the laboratory they are also pronouncedly cannibalistic, particularly the early instars. They can probably be fed on a wide variety of other insects but we fed them during the later stadia exclusively on a diet of scarab larvae and pupae of various species and during the early stadia on a diet of termites and Psocids. The latter were put into the Pyrophorus jars with the leaves and humus in which they were found.

In attacking scarab grubs the Pyrophorus seem not always to be motivated by hunger but by some sort of natural antipathy. On meeting with a grub in the bottom of an empty jar they almost invariably endeavor to bite it, but as far as has been observed they never continue to feed on the grub until both grub and Pyrophorus are covered with soil. The first bite of their attack seems to be impulsive and in the spirit of self defense, often hastily pinching the enemy in some soft portion of the body and quickly releasing it again. When thoroughly aroused, nevertheless, the Pyrophorus larva will often work the scarab grub between its jaws until these can be securely clamped on the head capsule of the grub. The hold is then seldom released until the capsule is crushed and the grub is put completely out of commission. As the larvae feed only in the soil they have not been actually observed in the act but the evidence of grub remains indicates that Pyrophorus feeds on the body tissues of the victim while gradually pushing itself into the body through a ragged hole chewed out in some anterior portion of the body wall. The head capsules and the thoracic and middle segments of the bodies of white grubs are usually found emptied but the hindmost ventral segments within which are found the dark contents of the gut are always left intact.

In Table III are given the laboratory feeding records of six field-collected larvae which were reared to full maturity under observation. Influenced greatly by the unavoidably meager and inconstant rate at which the larvae were fed, the data of this table give only an approximate idea of what the quantity of food may be which is essential to the complete development of Pyrophorus. The maximum number of white grubs which each Pyrophorus larva might destroy in the field is entirely a matter of guesswork and is probably a number more dependent on the density of scarab population, the consistency of the soil, and other factors than on the gastronomic capacity of Pyrophorus.

TABLE III

Showing the number of white grubs consumed by each of six field-collected Pyrophorus larvae kept until pupation in jelly jars partly filled with soil. As all the Pyrophorus were already approximately half grown when collected these records cover only the last half of any individual's life.

Lab. No. of Pyrophorus	Date of first feeding	Date of last feeding	Total number of days in laboratory	Number of grubs consumed	Avg. No. of days per grub
C1	4/ 8/33	4/ 9/34	365	69	5.3
C2	6/19/33	2/17/34	242	31	7.8
C3	4/24/33	3/14/34	323	61	5.3
C4	5/ 7/33	4/20/34	347	54	6.4
C5	3/29/33	3/10/34	345	55	6.2
C6	1/19/33	1/ 3/35	712	126	5.6
				Grand Average	6.1

In the laboratory, and probably also in the field under favorable conditions of grub abundance and accessibility, a great many more grubs are killed through being simply injured than are either partly or wholly consumed as food. Thus, when confined in a small jelly jar, four grubs a day were destroyed by one Pyrophorus larva every day for a period of two weeks.

As a rule a period of fasting is undergone by the larva of Pyrophorus just before each ecdysis. It may last from three to four days or may be prolonged to 10 or 12 and is often accompanied by perceptible diminution of the larva's activity. It is usually longest as a prelude to the inactive pre-pupal stage which precedes the last larval moult.

Pyrophorus vs. Scolia manilae:

It has been suggested that Pyrophorus might interfere with the usefulness of *Scolia manilae*, but we do not believe it can do so to any significant extent.

This belief is based principally on the following facts:

First: Due to the shortness of Scolia's larval stage in comparison to the total larval life of its host the chances that the host will be attacked by Pyrophorus during the critical period—that is, while the white grub is bearing the egg or the larva of Scolia—are relatively few.

Second: These chances are reduced through the fact that a considerable proportion of the white grubs parasitized by Scolia are found in deeper, harder soil than Pyrophorus is likely to frequent in the presence of the loose upper layer which almost universally covers a cultivated field and which as a rule harbors the majority of Anomala grub populations.

Third: The chances are further reduced through the invariably complete paralyzation of white grubs during the period when they are used as hosts by Scolia, and by the fact that during this period a large proportion of grubs lie in cavities whose walls are packed to a hardness considerably greater than that of the surrounding soil.

It has been determined that the larvae of Pyrophorus will attack and destroy both the active grubs of Anomala and those which have been paralyzed by the sting

of Scolia, but in the laboratory it has been found that in the presence of both paralyzed and active grubs the former are much less likely to be attacked than the latter.

It is not unreasonable to suppose that this same tendency will be found in the field, possibly more pronounced.

To determine the preference of Pyrophorus larvae for active or paralyzed grubs four large larvae were used. They were kept separately in small jelly tumblers partly filled with soil and each was provided daily with two third instar grubs of Anomala, one intact and one paralyzed by Scolia within the 12 preceding hours. The two grubs were in every case placed simultaneously in the bottom of the tumblers and the soil and Pyrophorus, previously removed, were put in afterwards. No grub, either intact or paralyzed, was used twice in the experiment and the slightest evidence of injury was taken as sufficient to place the particular grub in the "attacked" class. Observation and change of grubs were carried out at approximately the same hour for seven consecutive days and the results obtained were as follows:

Total number of white grubs used in the experiment...........	28 active and 28 paralyzed
Number of paralyzed grubs attacked by Pyrophorus...........	16
Number of active grubs attacked by Pyrophorus..............	25
Number of paralyzed grubs not attacked by Pyrophorus........	12
Number of active grubs not attacked by Pyrophorus...........	3

It is to be expected that Pyrophorus, once established in our cane fields and present in sufficient numbers, rather than interfering with the work of *Scolia manilae,* will supplement the work of the wasp in just such a manner as to reduce greatly the importance of the Anomala problem. The ability of the larvae of Pyrophorus to live and feed under the thick matting of cane which covers every field during the latter part of each ratoon, and which tends to impede the entrance of Scolia, may eliminate what is probably the principal cause of Anomala's lately heightened level of abundance.

Absorption of Mineral Nutrients by Sugar Cane at Successive Stages of Growth

By Arthur Ayres

The chemist is frequently called upon to assist in the solution of problems involving the subnormal growth of sugar cane. Such growth may have resulted either from pathological causes or from inadequate, or unbalanced, nutrient supply. The chemist assists in such work by determining the mineral composition of the specimens under consideration. By the same means, he has also been of assistance to the agriculturist in his studies of soil fertility. Studies such as these properly require comparison with normal or control canes in which all growth factors, other than the one under consideration, are identical. Often, however, such comparisons are impracticable, if not impossible. In such cases it has usually been necessary either to ignore, or to make generous allowances for, the effects of these growth factors upon the composition of the plant. For these reasons, a program of study was begun which would yield, in a degree, the understanding necessary to the interpretation of data resulting from such investigations.

Aside from the nutrient supplying power of the soil, the age of the cane plant is probably the greatest single factor influencing its mineral composition. In accordance with the program outlined above, the writer (1931-33) analyzed representative samples of sugar cane at periodic intervals from a plot set aside for the purpose at the Experiment Station. The results of this work showing the effect of age upon the composition of the cane plant were subsequently reported in *The Hawaiian Planters' Record* (2).

At the conclusion of the experiment, the remaining cane was harvested and a similar study of the succeeding ratoon crop begun. In the case of the ratoon crop, however, it was decided to investigate not only the effect of age upon the composition of the cane plant, but also the actual rates at which the principal mineral nutrients are taken into the plant. This was to be accomplished through periodic determination of the total quantities of nutrients contained in the stalk, green leaves and accumulated dead leaves of the cane plant. The purpose of this phase of the investigation was to obtain information which would reveal in greater detail than the earlier studies by Stewart (6) and by Stewart and the writer (1) the changing demands which the growing cane plant makes upon the soil for mineral nutrients. Knowledge of these demands at successive stages of growth would, it was felt, enable the agriculturist more nearly to adapt his program of fertilization to meet the needs of the crop. The present paper deals with the investigation of these matters in relation to the ratoon crop.

Experimental

The experimental plot consisted of approximately 1,000 running feet of cane in rows five feet apart. The variety of cane grown in the experiment was H 109, first ratoon. In order to avoid as far as possible any effect upon the rate of absorption of even temporarily localized concentrations of mineral nutrients, a soil (Field 8,

Makiki) was selected for the study which would require no fertilizer other than nitrogen to produce a normal crop of cane. The amounts of the principal nutrients present in the soil of the experimental plot, as measured by extraction with one per cent citric acid, are shown in Table I. The data, which are expressed in terms of pounds of nutrients per acre-foot of soil, indicate supplies of these materials which are generally considered adequate for the production of a crop of sugar cane.

TABLE I

POUNDS OF AVAILABLE NUTRIENTS IN SURFACE ACRE-FOOT OF SOIL*

Silicon (Si)	Calcium (Ca)	Potassium (K)	Phosphorus (P)
4,600	13,000	775	2,750

*It will be noted that the quantities of nutrients shown in the table are expressed in terms of the elements and not as the oxides of the elements, as is frequently done. There is a growing tendency among publishers and readers of scientific literature to insist upon the employment of the more fundamental unit of the element itself rather than of the oxide, or other compound of the element. This is manifestly the more logical procedure where, as in the present case, no attempt was made in the course of the analyses to determine the exact nature of the compounds in which the elements were present, but simply the quantities of the elements themselves. In so expressing the data, we have only reduced these nutrients to the same basis as that which has long been accepted in the case of nitrogen, which is always given in terms of the element rather than as one of its numerous oxides. That a truer picture of the relative quantities of nutrients taken up by the cane crop is obtained when we consider the elements themselves, in place of their oxides, will be seen by the following illustration. In Experiment E, Waipio (1), it was found that at the age of 12 months the stalks, green leaves and dead leaves in an acre of cane together contained 390 pounds of potash (K_2O) and 710 pounds of silica (SiO_2), or more than 4/5 again as much SiO_2 as K_2O. When, however, we express these quantities in terms of the elements we find that the amount of potassium (K) absorbed was 324 pounds and of silicon (Si) 332 pounds, or nearly equal amounts, which is quite a different picture. Conversion of data from one form to the other may readily be accomplished by means of the following factors: Ca=0.715 CaO; K=0.830 K_2O; P=0.437 P_2O_5; Si=0.467 SiO_2; Mg=.603 MgO.

Nitrogen in the form of ammonium sulfate was applied in amount corresponding to that which is generally used under similar field conditions by the plantations. A total of 200 pounds of nitrogen was applied as follows: August 24, 1933, 50 pounds; September 1, 1933, 50 pounds; December 26, 1933, 50 pounds; and September 24, 1934, 50 pounds.

The experimental area was planted in August 1931, and ratooned two years later in August 1933, when the present investigation was begun. The plot was sampled at monthly intervals, beginning one month after the start of the ratoon crop and continuing until the age of 14 months. Samples were selected in accordance with a carefully developed plan which was deemed well suited to the shape of the plot, the number of stalks to be removed per month and the total number to be harvested in the course of the study. Not more than a single stalk was cut from a stool of cane. Outside rows which were necessarily subjected to more light and wind than inner rows did not contribute to the samples. Thirty stalks were selected at each harvest during the first four months and subsequently 20 stalks. Specimens were selected from the normal, vigorous members of the original stand of cane.

Dry leaves appeared during the fourth month. Beginning with the fourth harvest, therefore, stalks to be cut at each succeeding period were tagged and stripped of adhering dry leaves. Hence, dry leaves present on the stalk at sampling one month later, plus those removed for safekeeping during the interim, represented the formation of this material during the preceding month. The crop passed through the first winter without tasseling. Extensive tasseling occurred the second winter and was already in evidence at the last period of harvest in October 1934.

Immediately upon cutting, the plants* were removed to the laboratory where the dead leaves, green leaves and stalks were separated. The plant material was then freed from extraneous matter by careful cleaning with dampened cloths. In order that the distribution of nutrients in the stalk might be studied, that part of the plant was divided into sections as indicated below:

From tip of growing point, 6 inches down stalk	Section A
From base of Section A, 3 feet down stalk	Section B
From base of Section B, 3 feet down stalk	Section C
From base of Section C, 3 feet down stalk	Section D
From base of Section D, 3 feet down stalk	Section E

This division was in part arbitrary and in part influenced by the results of earlier investigations.

Since the plants were severed at the surface of the ground, there was usually a section of each stalk which did not find a place in the above classification. These pieces comprised an additional sample which, like the other samples, was weighed and subsequently analyzed. Determinations of the composition of the roots were not made. Dry weights of all plant materials harvested were obtained. Because the immediate stages in the preparation of the plant materials for analysis were time-consuming, samples were taken early in the day. Frequently at these times the cane was thoroughly wet as a result of early morning showers. This situation was further aggravated as a result of transpiration losses by the leaves during the period required to obtain the samples and, in many instances, rendered futile attempts to secure accurate green weights. Sampling was discontinued at the age of 14 months. This was made necessary by the lodged and tangled condition of the cane at this age and the consequent impracticability of obtaining further representative samples.

Analytical Procedure

Determinations were made in duplicate upon the partially dried (1 to 5 per cent moisture) comminuted material by the methods given below:

Moisture: By drying to constant weight under vacuum at 80° C.

Ash: By overnight ignition in an electric muffle at 400° C.

Silicon: By the hydrofluoric acid method; occluded material remaining after destruction of the silicon being added to the filtrate from the silicon.

Calcium: By removal of silicon, iron, aluminum, and phosphorus from the hydrochloric acid extract of the ash and volumetric determination of calcium as the oxalate.

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* For lack of a proper name the word "plant" is frequently used in this paper to designate the aerial portion of the cane stalk plus the accompanying leaves.

Magnesium: By the removal of silicon, iron, aluminum, phosphorus, and calcium from the acid extract of the ash and determination of magnesium by double precipitation of magnesium ammonium phosphate and subsequent ignition to magnesium pyrophosphate.

Potassium: By the removal of silicon, iron, aluminum, phosphorus, and calcium from the hydrochloric acid extract of the ash and the determination of potassium by the Lindo-Gladding method (as potassium chloroplatinate).

Phosphorus: By separation with iron from the hydrochloric acid extract of the ash (following removal of silicon) and subsequent determination by the volumetric ammonium molybdate method.

Nitrogen: By the Gunning method for total nitrogen.

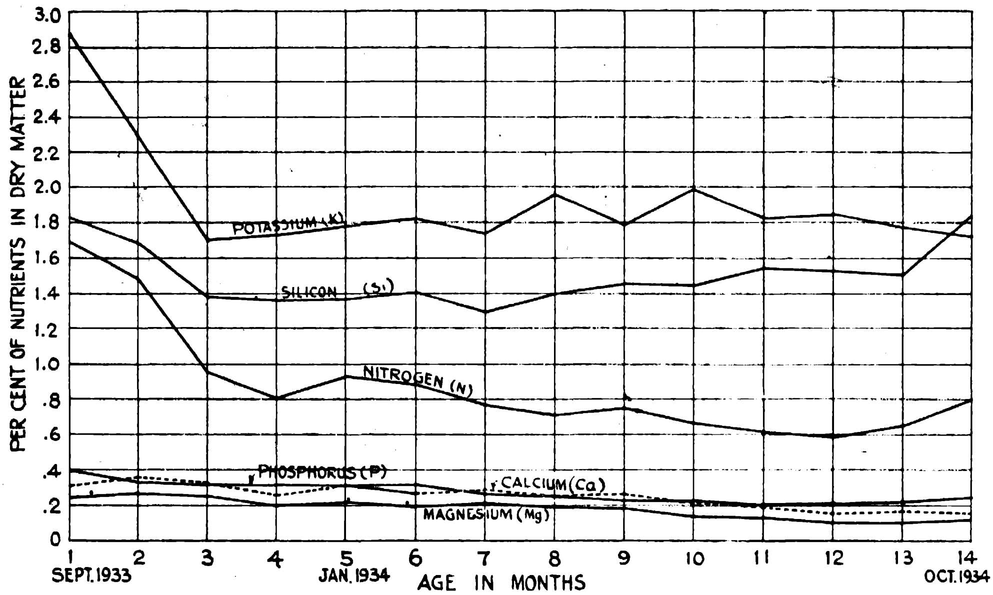

Fig. 1. This chart shows the changes which took place with age, in the mineral composition of the green leaves.

Discussion

Effect of Age Upon the Percentage Composition of the Green Leaves:

In Table II and in Fig. 1 is shown the percentage composition of the dry matter of the green leaves, at intervals of a single month, from one to 14 months. Referring to the figure, it will be observed that marked decreases in the concentrations of potassium, silicon, nitrogen, and phosphorus occurred during the first three to four months of growth. Between this period and the age of one year, changes were generally less pronounced. During the final two months of the experiment, the percentages of several of the nutrients in the leaves increased. These final changes appear to have been associated with the preparation of the plant to tassel. The increase in nitrogen during this period was doubtless, in part at least, the result of an application of ammonium sulfate to the experimental plot at the age of 13 months. It is of interest to note that whereas the percentages of the three principal mineral

constituents of the leaves and of phosphorus decreased during the initial months of growth, those of calcium and magnesium increased slightly during the same period. The same dissimilarity was observed in the plant crop and indicates an early rapid movement of these two bases into the leaves. With the exception of silicon, the changes with age in the composition of the leaves of the ratoon crop were similar to those observed in the plant crop.

TABLE II

PERCENTAGE COMPOSITION OF DRY MATTER

Age	Ash	Si	Ca	K	Mg	P	N
Age	Ash	Si	Ca	K	Mg	P	N
			STALKS				
2 months	13.67	.23	.46	3.39	1.13	.85	2.36
3 months	8.42	.38	.29	2.19	.60	.49	.93
4 months	6.06	.42	.16	1.59	.33	.37	.48
5 months	4.45	.33	.093	1.19	.21	.26	.44
6 months	3.57	.28	.064	1.00	.15	.22	.36
7 months	2.65	.23	.058	.70	.13	.17	.22
8 months	2.33	.20	.044	.59	.10	.15	.18
9 months	2.10	.18	.041	.55	.097	.14	.15
10 months	2.03	.16	.037	.50	.078	.14	.13
11 months	2.03	.21	.049	.46	.097	.16	.10
12 months	1.80	.16	.039	.46	.078	.14	.092
13 months	1.65	.16	.036	.40	.072	.14	.098
14 months	1.73	.17	.038	.42	.072	.14	.12
			GREEN LEAVES				
1 month	11.40	1.84	.31	2.89	.25	.40	1.70
2 months	10.29	1.69	.36	2.30	.27	.33	1.49
3 months	8.28	1.38	.33	1.70	.25	.31	.94
4 months	8.02	1.36	.26	1.73	.20	.31	.80
5 months	8.16	1.36	.32	1.78	.22	.31	.93
6 months	8.38	1.40	.26	1.81	.19	.31	.88
7 months	7.82	1.29	.29	1.74	.21	.27	.77
8 months	8.45	1.39	.25	1.96	.19	.25	.71
9 months	8.37	1.45	.26	1.78	.18	.23	.75
10 months	8.03	1.44	.20	1.99	.14	.22	.66
11 months	8.03	1.54	.19	1.82	.13	.21	.62
12 months	7.66	1.52	.16	1.85	.10	.19	.58
13 months	7.77	1.55	.16	1.77	.10	.23	.65
14 months	8.38	1.83	.16	1.72	.12	.24	.80
			DEAD LEAVES				
4 months	11.62	3.28	.59	.46	.35	.21	.29
5 months	8.64	2.16	.42	.56	.28	.20	.26
6 months	8.72	2.19	.39	.60	.25	.25	.26
7 months	8.15	2.05	.41	.71	.27	.26	.27
8 months	8.45	1.97	.38	.88	.27	.24	.22
9 months	8.82	2.16	.43	.81	.27	.16	.21
10 months	8.98	2.44	.41	.79	.25	.14	.22
11 months	8.72	2.41	.35	.81	.21	.14	.18
12 months	8.45	2.37	.30	.90	.16	.10	.18
13 months	7.72	2.39	.29	.53	.14	.12	.18
14 months	8.08	2.61	.25	.64	.14	.13	.13

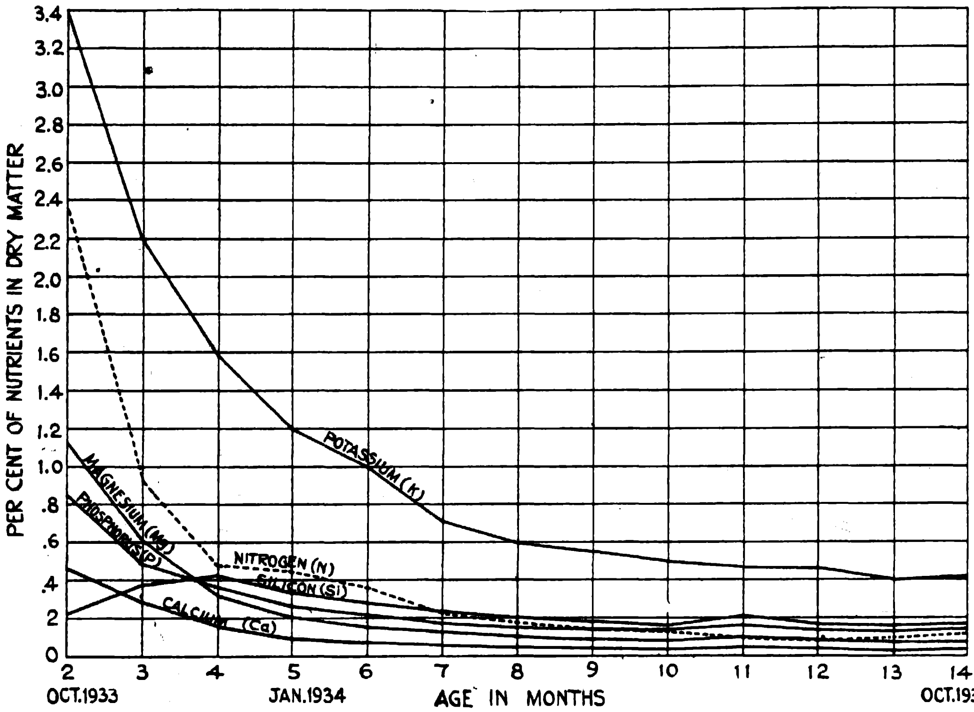

Fig. 2. Showing the changes which occurred with age in the mineral composition of the stalk.

Changes With Age in the Percentage Composition of the Stalk:

The changes which took place in the composition of the stalk as the crop developed were much more pronounced and operated over a longer period of time than the more rapidly maturing leaves. These changes are illustrated in Table II and in Fig. 2. Referring to the figure, it will be observed that the percentages of all elements but silicon decreased consistently up to eight or more months. After reaching a maximum at four months, the percentage of this element likewise decreased. Potassium was less prone than the other elements to reach a constant value and there is reasonable doubt that such a value had been attained, even by the end of the experiment. There seems little question, however, but that the other elements had ceased to decrease by the end of the first year. In earlier, related studies in Hawaii (1, 6), changes in the concentrations of nutrients in the stalk have been observed at ages considerably greater than those at which constant values were obtained in the present experiment. This difference possibly results from the fact that, in the previous studies referred to, samples taken for analysis were so selected as to approximate the composition of the millable cane as a whole and hence contained some stalks younger than the age of the experiment would indicate whereas, in the present investigation, sampling was confined to the original stand of cane.

From the foregoing discussion it is apparent that the mineral compositions, both of the leaves and of the stalk of sugar cane, are very definitely functions of the age of the plant. Hence, if any significance is to be attached to data relating to the mineral composition of the cane plant, it should be done only in view of the age of the plant. This is true whether the composition of the specimen is to be employed

as an index to the nutrient status of the soil, or for comparison with other (normal) specimens, as in physiological or pathological studies.

Translocation of Nutrients in the Leaves:

If a comparison is made of the compositions of the dry matters of the green and dead leaves (see Table II) it will be seen that the former contain much higher percentages of potassium and nitrogen, and generally greater percentages of phosphorus, than the latter. If we may assume that the dead leaves which accumulated between any two periods of harvest were once even roughly similar in composition to the green leaves harvested at the same period, then we have evidence of the substantial translocation of these nutrients from the green leaves back into the stalk. It might be argued that this does not prove translocation, since the mass of green leaves at each harvest contained many young, succulent members which, on a dry-weight basis, would be expected to contain larger proportions of these nutrients than the dry leaves. If this were the correct explanation, we should expect to find the dry matter of the green leaves richer also in such elements as calcium, magnesium, and silicon. The reverse, however, is the case.

In a recent investigation of the composition of the individual leaves of the cane plant, the author found that generally the older the leaf the higher the concentrations (expressed on the dry-weight basis) of silicon, calcium, and magnesium, whereas the reverse was true of nitrogen and potassium. The behavior of phosphorus in this connection was indefinite. From these observations also, the suggestion is strong that large proportions of the nitrogen and potassium contained in the green leaves migrate back to the stalk before the leaves become physiologically inactive. Such migration in the cane plant in the instance of potassium has previously been observed by Boname (3), Hartt (5), and van Houwelingen (7). The last mentioned obtained evidence also of the migration of nitrogen and phosphorus.

Uptake of Nutrients by the Growing Crop:

In the following discussion the demands made upon the soil for plant nutrients by the growing cane crop and the distribution of the absorbed nutrients within the several phases of the crop are considered. The quantities of nutrients and of dry matter contained in the green leaves, dry leaves, stalk and entire plant, at successive ages, are shown in Table III. The data are presented upon the basis of the number of grams of nutrients, and of dry matter, present in a single plant or part thereof. The data are also shown in more readily comprehensible forms in Figs. 3 to 9.

Calcium: Referring to Fig. 3, it will be seen that calcium was taken up by the cane plant at a rate which increased rapidly during the initial stages of growth and which attained a maximum value at the early age of three months. The rate of absorption reached at this point was generally maintained until the age of about nine months when it commenced to diminish. The quantity of calcium contained in the green leaves increased until the age of five months when it became constant. A later decrease in the calcium content of the green leaves was coincident with the slight drop in the rate of absorption already noted. The importance of considering the dead leaves in a study of this type—a factor frequently neglected—is well illus-

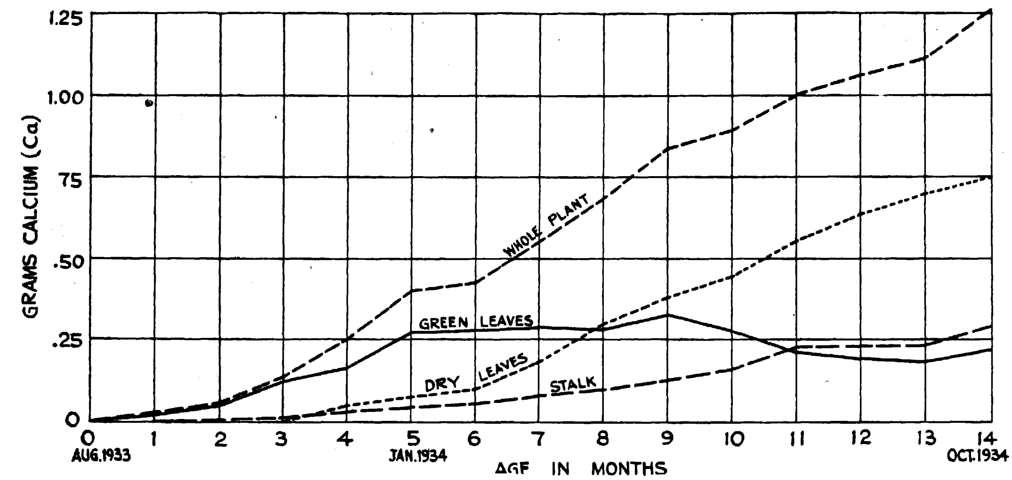

Fig. 3. Showing the rate at which calcium was taken up by the cane plant and the distribution of this nutrient among the several components of the crop.

trated in the present experiment. Referring to Fig. 3, it will be seen that at the final harvest, the accumulated dead leaves contained 1½ times as much calcium as the entire standing crop.

TABLE III

GRAMS OF NUTRIENTS AND OF DRY MATTER CONTAINED IN THE CANE PLANT AT AGES OF FROM 2 TO 14 MONTHS

Age, months	Grams of Si	Ca	K	Mg	P	N	Dry matter
			GREEN LEAVES				
2	0.26	0.054	0.35	0.039	0.050	0.23	15
3	0.51	0.12	0.63	0.093	0.11	0.35	38
4	0.84	0.16	1.06	0.12	0.19	0.50	62
5	1.14	0.27	1.49	0.18	0.26	0.77	84
6	1.49	0.28	1.93	0.21	0.33	0.94	107
7	1.34	0.29	1.79	0.21	0.28	0.80	104
8	1.56	0.28	2.21	0.21	0.29	0.81	112
9	1.84	0.33	2.26	0.23	0.29	0.95	127
10	1.99	0.28	2.75	0.19	0.30	0.93	138
11	1.73	0.21	2.05	0.15	0.24	0.70	113
12	1.77	0.19	2.16	0.12	0.22	0.68	117
13	1.74	0.18	1.98	0.12	0.25	0.73	112
14	2.47	0.22	2.32	0.17	0.33	1.09	135
			DRY LEAVES				
4	0.29	0.050	0.042	0.030	0.020	0.025	8.8
5	0.43	0.079	0.079	0.048	0.033	0.040	15
6	0.57	0.10	0.12	0.066	0.050	0.060	22
7	0.95	0.18	0.25	0.11	0.098	0.11	40
8	1.60	0.30	0.53	0.20	0.17	0.18	73
9	2.04	0.38	0.70	0.26	0.21	0.22	93
10	2.46	0.45	0.83	0.30	0.23	0.26	110
11	3.22	0.56	1.09	0.36	0.28	0.32	142
12	3.81	0.64	1.32	0.40	0.30	0.36	167
13	4.33	0.70	1.43	0.43	0.33	0.40	188
14	4.79	0.75	1.56	0.46	0.35	0.43	208

Age, months	Si	Ca	K	Mg	P	N	Dry matter
				Grams of			
			STALK				
2	...	0.004	0.012	0.006	0.004	0.010	0.4
3	0.016	0.011	0.091	0.024	0.020	0.040	4.2
4	0.091	0.036	0.35	0.072	0.081	0.11	22
5	0.16	0.046	0.59	0.10	0.13	0.22	49
6	0.24	0.054	0.85	0.13	0.19	0.30	85
7	0.34	0.082	1.00	0.18	0.25	0.32	130
8	0.45	0.10	1.34	0.24	0.34	0.41	229
9	0.55	0.13	1.70	0.30	0.43	0.48	312
10	0.72	0.16	2.14	0.34	0.62	0.54	425
11	0.97	0.23	2.15	0.45	0.77	0.48	471
12	1.11	0.23	2.86	0.45	0.92	0.61	579
13	1.07	0.23	2.59	0.46	0.88	0.64	649
14	1.33	0.29	3.20	0.58	1.05	0.89	765
			WHOLE PLANT*				
2	0.26	0.058	0.36	0.045	0.054	0.24	16
3	0.53	0.13	0.72	0.12	0.13	0.39	42
4	1.22	0.25	1.45	0.22	0.29	0.63	93
5	1.73	0.40	2.16	0.33	0.42	1.03	148
6	2.30	0.43	2.90	0.41	0.57	1.30	214
7	2.63	0.55	3.04	0.50	0.63	1.23	274
8	3.61	0.68	4.08	0.65	0.80	1.40	414
9	4.43	0.84	4.66	0.79	0.93	1.65	532
10	5.17	0.89	5.72	0.83	1.15	1.73	673
11	5.92	1.00	5.29	0.96	1.29	1.50	726
12	6.69	1.06	6.34	0.97	1.44	1.65	863
13	7.14	1.11	6.00	1.01	1.46	1.77	949
14	8.59	1.26	7.08	1.21	1.73	2.41	1,108

* Green leaves, dry leaves and stalk.

Magnesium: Absorption of magnesium by the cane plant as a whole practically paralleled that of calcium at all stages of growth, as may be seen by a comparison of Figs. 3 and 4. A marked distinction appears, however, in the distribution of these two nutrients within the plant. Thus, at all stages of growth, much larger proportions of the absorbed magnesium than of calcium were present in the stalk. Conversely, larger proportions of calcium than of magnesium were contained in the leaves.

Phosphorus: Reference to Fig. 5 will show that absorption of phosphorus was relatively slight during the initial three months of growth. Less than 10 per cent of the quantity absorbed in the course of the first year was taken up during this period. Subsequently, phosphorus was absorbed by the cane plant at an increased rate which remained practically constant until the conclusion of the experiment. This finding supports, in part, that of an earlier investigation (1) in which it was similarly found that phosphorus was taken up by the cane crop at a rate which was essentially constant after the initial three months of growth. As in the case of magnesium, there was no increase in the content of this nutrient in the green leaves after six months.

Phosphorus was found to be present in the stalk to a relatively greater extent than were any of the other nutrients studied. More than half of the absorbed phos-

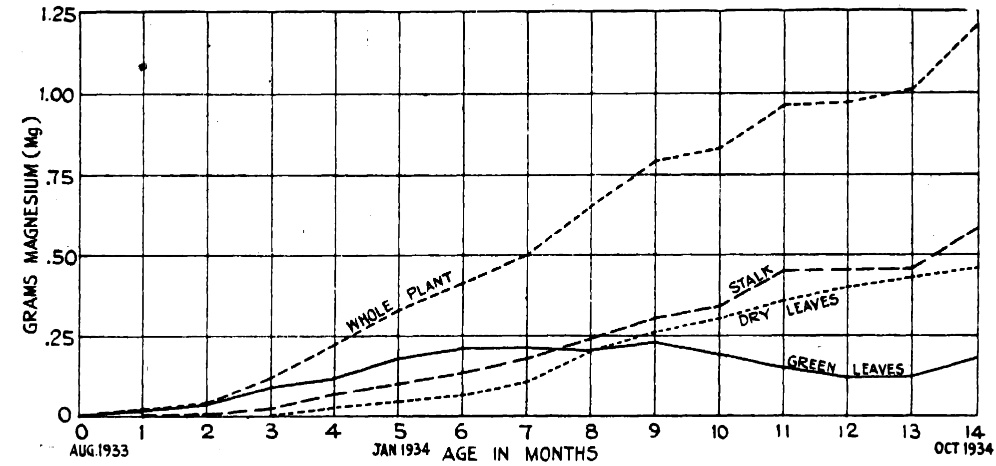

Fig. 4. Magnesium was absorbed at practically the same rate as calcium. The distribution of these two nutrients among the stalks, green leaves and dry leaves, however, was very different.

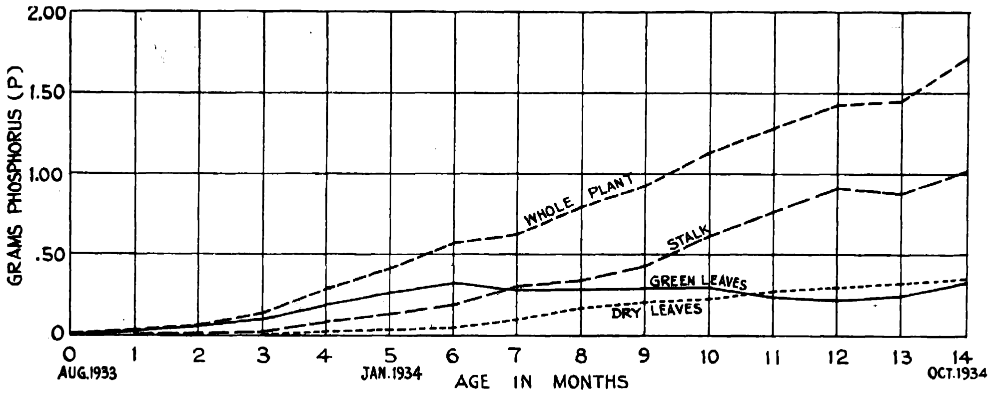

Fig. 5. Showing the rate at which phosphorus was taken up by sugar cane. Phosphorus was found to be present in the stalk to a greater degree than were any of the other elements for which analysis was made.

phorus was present in this organ of the plant after the age of seven months. Since the tops and trash normally remain in the field at harvest, it is the quantities of nutrients present in the stalk which measure the permanent loss of a nutrient to the field through cropping.*

Silicon: Reference to Fig. 6 shows that absorption of this constituent of the ash was very rapid following the first three months of growth, reaching, at seven months, a rate which remained practically constant throughout the remainder of the experiment. In contrast to the cases previously considered, the silicon content of the green leaves did not reach a maximum until the age of 10 months. Only a small proportion of the silicon absorbed by the cane plant was found in the stalk at any period of harvest. At the final sampling (14 months) it amounted to but 15 per cent of the total taken up. Thus, although sugar cane takes up very large quanti-

* An exception to this statement must be noted in the case of nitrogen, since a large proportion of the nitrogen contained in the tops and in the trash is lost through preharvest and postharvest burnings.

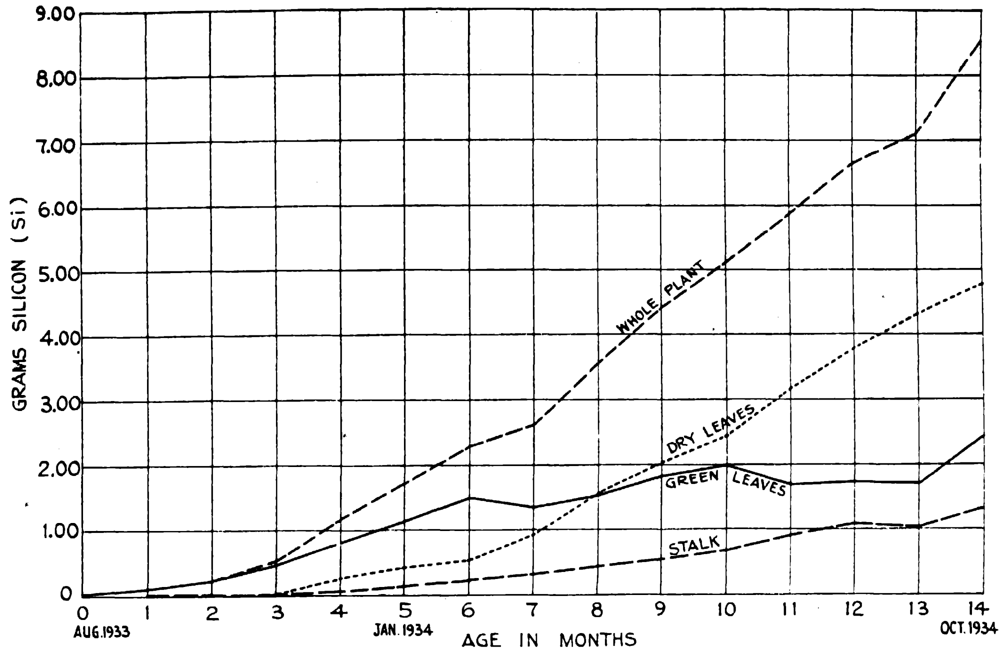

Fig. 6. Silicon was taken up in larger amount than any other mineral element. Relatively little silicon remained in the stalk. Most of it passed through to the leaves, where it was lost to the plant as the older leaves died and were cast off.

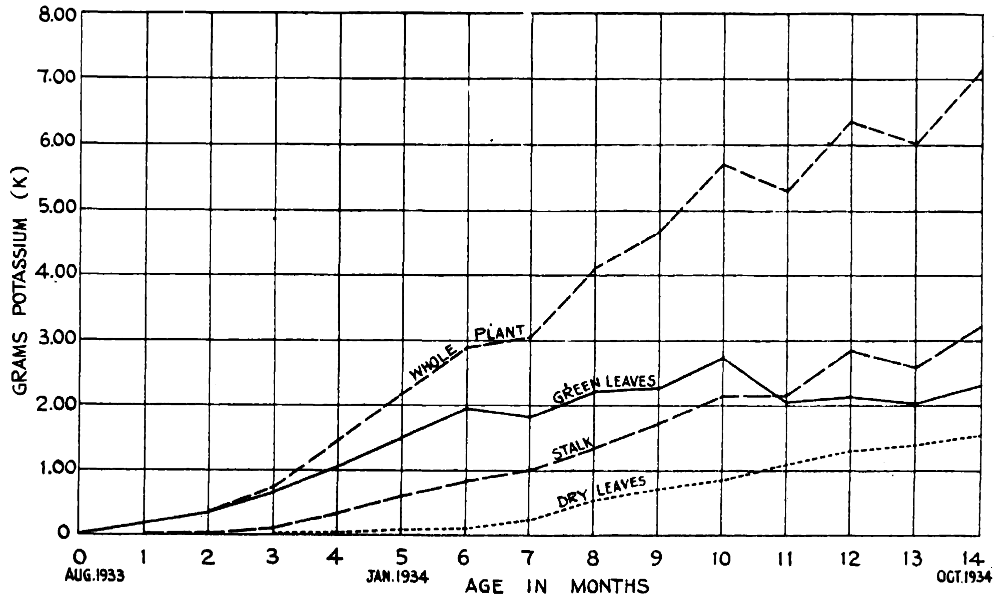

Fig. 7. This graph shows the rate at which the sugar cane absorbed potassium. The distribution of this nutrient among the several components of the crop is also shown.

ties of silicon, relatively little is permanently lost to the field through cropping. As in the case of calcium, more silicon was present in the accumulated dead leaves at the final harvest than in the entire living crop.

Potassium: Referring to Fig. 7, it will be seen that the rate of absorption of potassium by the cane plant, like that of most of the other nutrients considered, attained a maximum at the age of three months. During this period only 11 per cent of the first year's uptake of the nutrient occurred. The rate reached at this point was generally maintained until the age of 10 months, when it commenced to diminish. It will be observed that this reduction in the absorption of potassium by the plant coincided with the acquirement by the green leaves of their maximum content of the nutrient. Or, to state it in the reverse manner, the reduced need of the leaves for potassium was reflected in diminished absorption of the nutrient. Potassium was present in the stalks of the older canes in relatively smaller degree than was phosphorus. Hence, loss of potassium from the soil through cropping would be proportionately less than in the case of phosphorus.

The findings of this investigation relative to absorption of potassium by the plant are generally in harmony with those of Stewart (6) who found that this nutrient was taken up very rapidly by sugar cane between the ages of three and eight months, but at a much slower rate during the remainder of the first year. In a later investigation (1), potassium was found to be absorbed at a rapid rate between the ages of three and 12 months, but at a greatly reduced rate after 12 months. Work now in progress in this laboratory indicates that the demand made upon the soil for potassium by the variety of cane grown in this experiment (H 109) is greatly exceeded by that of certain other varieties.

Referring to Fig. 9, in which is shown the growth of the cane plant, as measured by the formation of dry matter, it will be observed that an era of rapid growth began at about the age of seven months and continued until the end of the experiment. It might be expected that the commencement of this period of enhanced development would mark a corresponding increase in the uptake of potassium. Referring to Fig. 7, it will be seen that this was not the case. Moreover, while the absorption of potassium diminished after the tenth month, as has been pointed out, there was no corresponding diminution in the rate of growth of the cane plant. Hence, it appears that *the rate at which potassium is absorbed by sugar cane is not primarily a function of the rate of growth, but of the age, or of the stage of development of the plant.* This appears to be true of other elements also, particularly calcium, magnesium, and nitrogen.

Nitrogen: The rapid rate at which nitrogen was absorbed during the first three months of growth contrasts strikingly with the relatively much slower uptake of the other nutrients studied. Nearly one-quarter of the nitrogen absorbed in the course of the entire first year was taken up during the initial three months of growth. Absorption of nitrogen continued at a rapid rate until the age of six months was reached, when it generally diminished. A sharp increase in the uptake of this nutrient between 13 and 14 months was coincident both with an application of ammonium sulfate to the experimental area and with the preparation of the plant to tassel. Interpretation of this abrupt rise in the rate of absorption in the last month of the experiment is complicated by the possibility that both of these factors were involved. It appears probable, however, that the ammonium sulfate added at

the age of 13 months was largely, if not wholly, responsible for the subsequently increased rate of absorption of nitrogen. As in the case of phosphorus and certain other nutrients, the quantity of nitrogen in the green leaves did not increase after the age of six months.

With the nutrients previously considered, we have assumed, upon the basis of our analysis of the soil, that at all periods of growth substantial quantities of these substances were available to the crop. In the case of nitrogen, however, we cannot safely make such an assumption. Particularly is this true in view of the increase in the absorption of this nutrient following its application to the soil at 13 months. From the work of Das and Cornelison (4), and from the more recent studies of Q. H. Yuen (at this Station) and of the author, it appears probable that the sharp reduction in the rate of absorption of nitrogen at six months was associated with an abrupt and marked lowering of the supply of available soil nitrogen at that point. It is probable, therefore, that the uptake of nitrogen by the plant between the ages of 6 and 13 months (when ammonium sulfate was added) does not represent the maximum absorption of which the plant was capable.

Whatever the cause of the reduced uptake of nitrogen at this comparatively early age of the crop, there was no corresponding effect upon the growth of the plant, as will be seen by a comparison of Figs. 8 and 9. In fact, the maximum rate of growth of the crop did not obtain until shortly *after* the absorption of nitrogen began to fall off. Moreover, growth continued at this maximum rate throughout the succeeding seven months or until the conclusion of the experiment.

As will be seen by reference to Table 11, the continued normal growth of the plant, under conditions of reduced uptake of nitrogen, was associated with a greater nitrogen economy in subsequently formed leaves and stalk, that is, until nitrogen was again applied at 13 months. There was also some evidence that nitrogen which entered the stalk during the period of rapid uptake of the element was subsequently reutilized in the formation of new tissue.*

Further evidence that the cane crop takes up the bulk of its nitrogen during the early months of growth is shown by the results of an experiment conducted at Oahu Sugar Company, Ltd. (1927-1929). Relative to the uptake of nitrogen by the crop, Stewart (6) states, "By the eighth month of the crop's growth . . . all the plots had taken up the largest part of the crop's total supply of nitrogen. There was a further gradual abstraction, but the most rapid absorption took place in the early months of the growth of the crop." In this experiment a little more than 2/3 of the total amount of nitrogen received by the crop was applied during the first six months of growth. A most striking example of the ability of the cane plant to continue the production of millable cane over a period of months without further appreciable uptake of nitrogen is provided in an experiment conducted at the Waipio substation 1928-29 (1). In this experiment, in which all of the nitrogen was applied during the first six months of growth, the crop at 24 months apparently contained no more nitrogen than at 12 months. Yet, the yield of millable cane increased during that period from a little over 50 tons to nearly 100 tons.

It appears, therefore, that what was found to be true of potassium and certain other elements is even more true of nitrogen, namely, that the rate of uptake of

* See "Translocation of Nutrients in the Stalk" in this paper.

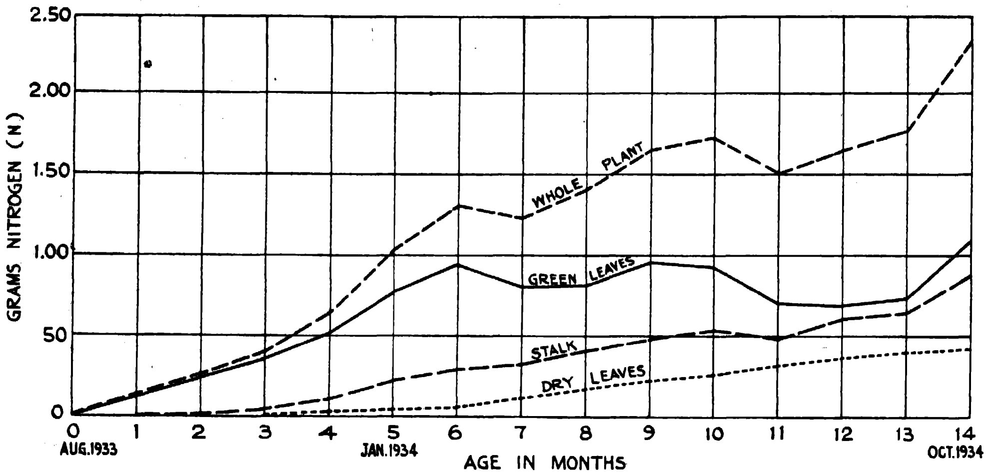

Fig. 8. Nitrogen was taken up very rapidly during the first six months of growth. From this point, until the age of 13 months was reached, and during which no nitrogen fertilizer was added, absorption was relatively slight. Rapid uptake of the nutrient followed fertilization with nitrogen at 13 months.

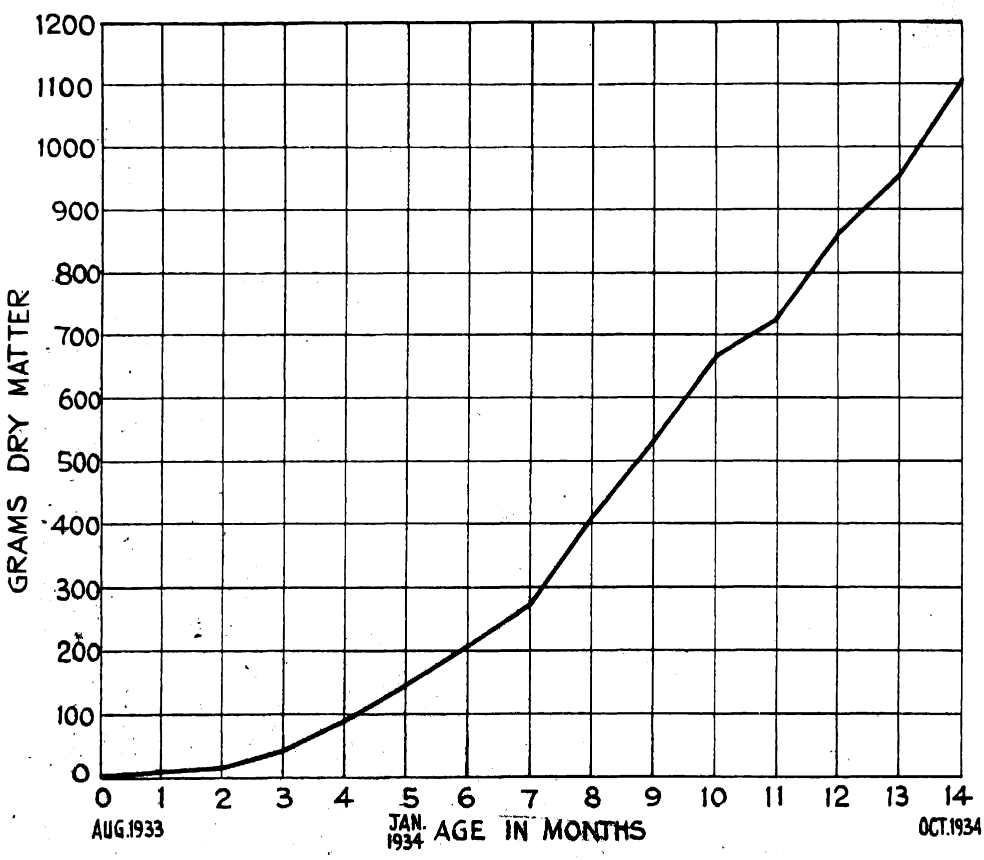

Fig. 9. Showing the growth of the cane plant as measured by the increase in total dry matter.

nitrogen by sugar cane, at least under the conditions of limited supply usually present in the field, bears little relation to the rate of growth of the crop. Rather does the plant absorb nitrogen very rapidly during the early months of growth, or until the leaves and the green-leaf portion of the stalk, which are rich in nitrogen, have become well established. Following the attainment of this stage of development, very much smaller quantities of the nutrient apparently suffice to carry the crop to maturity. In this connection it will be recalled that much of the nitrogen contained in the green leaves migrates back to the stalk before the leaves die. The subsequent reutilization of this nitrogen doubtless enables the crop to grow with a lower uptake of nitrogen than would otherwise be required.

Distribution of Nutrients in the Stalk:

An interesting picture of the manner in which the mineral nutrients are distributed throughout the length of the stalk is given in Fig. 10. The heights of the columns shown in the chart represent the quantities of nutrients in successive three-foot sections of the stalk. Referring to the figure, it will be seen that calcium is fairly evenly distributed throughout the 12-foot length of stalk there represented. To a slight extent, the quantities of nitrogen, and in a very marked degree, those of magnesium, phosphorus, and silicon increase per unit length of stalk as the base of the stalk is approached. With potassium, exactly the reverse is the case, the

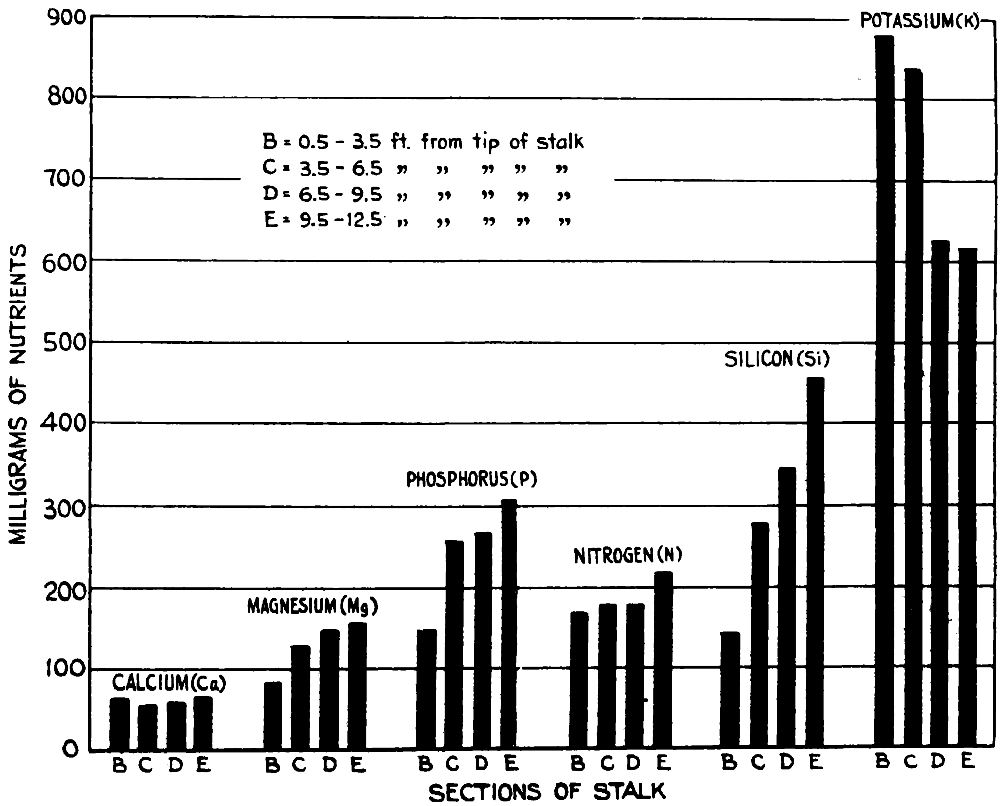

Fig. 10. This chart shows the distribution of nutrients in successive three-foot sections of the stalk of sugar cane at the age of 14 months. It will be noted that potassium decreases as the base of the stalk is approached, whereas the other elements tend to increase.

amount of this nutrient per unit length of stalk being greatest in the upper portion of the stalk where cellular activity is at a maximum.

Translocation of Nutrients in the Stalk:

Periodic examination of the total quantity of a nutrient in a definite portion of the cane stalk makes it possible to determine whether or not any changes are occurring in the nutrient content of that portion of the stalk as the plant develops. This was done in the present investigation by comparing the amounts of nutrients contained in three-foot segments of stalk formed during the early months of the experiment with corresponding sections (that is, formed during the same period) harvested later in the experiment. While the data pertaining to this matter are not as extensive as might be desired, they appear to indicate that as the younger tissues of the stalk mature they lose nitrogen and potassium through the upward migration of these nutrients. This movement was more pronounced in the case of potassium than in that of nitrogen. In contrast, silicon and phosphorus were found to accumulate as the tissue became older. Neither translocation nor accumulation of either calcium or magnesium in the stalk was observed. Translocation of potassium in the stalk of the cane plant has previously been observed by Boname (3), by the author (2) and by others.

Summary

A study has been made of changes which occur with age in the mineral composition of the sugar cane plant and of the uptake of the several nutrients with respect to the age of the crop.

It was found that the percentage compositions of the leaves and of the stalk of the cane plant are markedly influenced by the age of the plant, particularly during the early months of growth. Hence, the indiscriminate utilization of data pertaining to the percentage composition of the cane plant may prove fallacious.

The dry matter of dead cane leaves was found to contain much lower concentrations of potassium and nitrogen, and somewhat lower percentages of phosphorus than that of green leaves. This is accounted for on the basis that these nutrients migrate from the leaves back to the stalk before the leaves become physiologically inactive.

The cane plant was found to absorb the principal mineral nutrients in widely different amounts. Potassium and silicon were taken up to the greatest extent, while nitrogen and phosphorus were absorbed in relatively moderate quantities. Of the nutrients studied, calcium and magnesium were absorbed in least amount.

The rates at which the several mineral nutrients were absorbed were found to vary with the age of the plant, but not always in the same degree for each nutrient. The rates of absorption of all the elements studied, with the exception of silicon, reached maximum values by the early age of three months. During this period approximately 10 per cent of the first year's uptake of phosphorus and potassium occurred. The corresponding quantity of nitrogen was much greater, amounting to nearly 25 per cent. After the age of six months, in the case of nitrogen, and after about 10 months, in the cases of calcium, magnesium, and potassium, the rates of absorption diminished. Uptake of silicon and phosphorus, on the other hand,

continued at essentially constant rates until the conclusion of the experiment at 14 months.

The rates of absorption of potassium and nitrogen were found to decrease immediately following the acquirement of maximum quantities of these nutrients by the green leaves.

From the results of this study it is apparent that absorption of nitrogen and potassium, and in less marked degree, that of certain other nutrients, by sugar cane is not primarily a function of the rate of growth, but of the age, or of the stage of development, of the plant.

Pronounced differences were found in the distribution of the elements among the components of the crop. These differences were most marked in the instances of phosphorus and silicon. The quantities of these nutrients in the stalk (at the final harvest) amounted to 60 and 15 per cent, respectively, of the totals taken up by the plant.

Periodic examination of the quantities of the several nutrients contained in given segments of the stalk indicates that as the younger tissues of the stalk mature they lose potassium and nitrogen through the upward migration of these nutrients.

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Chemical Analyses as an Aid in the Control of Nitrogen Fertilization

By Q. H. Yuen and R. J. Borden

Foreword

Soil analysis as one of the aids to the fertilization of Hawaiian soils for sugar cane culture has been simplified somewhat by rapid chemical analytical methods. Due to the ease and rapidity with which determinations may be made, many of the soil testing assemblies developed at the Experiment Station have been widely adopted for use on plantations by resident agriculturists and other workers.

Of the several major R.C.M. (rapid chemical methods) soil testing assemblies, the soil phosphate and soil potash units, which are in general use, have made it possible to correlate data in R.C.M. soil studies with those obtained in other soil chemical investigations and also with Mitscherlich soil tests and field experiments. These correlations have been used as guides in fertilization of many plantation soils with phosphate and potash.

Following requests for a simplified procedure whereby the available nitrogen in soils may be evaluated in a manner similar to the R.C.M. determinations of phosphate and potash (with corresponding analytical equipment) the chemistry department of the Experiment Station has developed (among others) a method and assembly for the rapid estimation of ammonia and nitrate nitrogen in soil (16, 17). The sum of these two forms of soluble nitrogen, when thus determined, is taken as a measure of the concentration of the nitrogen in the soil which is available at the *moment* of analysis.

In order to augment a none too thorough understanding of the practical application of soil nitrogen data accruing from rapid chemical analyses, and to acquire additional information from studies employing this newer method of analysis, further researches have been made by Q. H. Yuen and R. J. Borden upon the availability status of nitrogen in Hawaiian soils and the nitrogen phase of soil-plant relationships. Supplementing investigations conducted on plantations by individual agriculturists, the agricultural and chemistry departments of the Experiment Station have cooperated in conducting a number of pot experimental studies at Makiki, the results of which are presented in this paper.

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The present study embraces two aspects of the nitrogen problem: the soil variations and the soil-plant relationships. The soil studies include measurements of the rates of nitrification and of the variability in the amounts of available nitrogen under conditions both with and without plant growth. The pot experiments with cane and other crops were designed and conducted to yield information relevant to the absorption of nitrogen by the crop, and to the relation of known nitrogen fertilization to yield and crop composition.

A review of the literature has indicated that numerous local studies on diverse phases of the nitrogen problem have been made which have yielded data and information of a fundamental nature. The biochemical aspects have received the attention of Peck (28, 29, 30), McGeorge (25) and Heck (18), who investigated the effect of the addition of molasses on the availability of soil nitrogen and upon nitrification in Hawaiian soils. Kelley (19), Burgess (7) and McGeorge (23, 24) have reported studies based upon the nitrification processes as a measure of soil fertility. The retention of nitrates by Hawaiian soils has been investigated by Stewart and Hansson (34). The loss of nitrates by leaching from fallow pineapple soils has been discussed by Magistad (22). The relation between nitrogen and organic matter has been made the subject of investigational research by Dean (9). Studies of the relation of nitrogen fertilization to the yield and composition of the cane crop have been reported by Alexander (2), Ayres (4, 5) and Das and Cornelison (8).

Experimental

Methods of Analyses:

The rapid chemical method (R.C.M.) for the determination of available nitrogen in soils is described by Hance (16) as one which consists of extracting a measured amount of soil with a dilute aqueous solution of potassium sulfate. By the process of base replacement and water solution, the ammoniacal and nitrate nitrogen are obtained in the extract. The two forms of nitrogen are determined in separate aliquots by colorimetric methods.

Total nitrogen in soils and plant materials was determined respectively by the official Gunning method and the Gunning method modified to include the determination of nitrate nitrogen (3).

Pot Tests:

The Mitscherlich pots and technic were used since these eliminated the factor of loss of nutrients by leaching. In all cases, to both the cropped and uncropped soils, water was applied in moderate amounts. When an excess was required, as in the case of plants reaching maturity, the drainage or leachate was returned to its respective pot. Where sugar cane was the crop grown, plantings of two shoots per pot were made from one-eye cuttings of seed pieces germinated in sand boxes and started for a period of four weeks before transplanting. Sudan grass plantings were made directly from seeds and the seedlings were thinned soon after appearing above ground to leave 40 plants in each pot.

Soil Studies

Incubation Tests (soils without crop):

Incubation tests were conducted by placing in Mitscherlich pots 4½ kilograms of air-dry soils to which were added in solutions, 9 grams P_2O_5 from superphosphate and 1½ grams K_2O from potash sulfate. When nitrogen was supplied, this nutrient was applied from an ammonium nitrate solution. All fertilizers were mixed into the soil before potting. Soil samples were taken periodically from these uncropped pots and determinations of available nitrogen in the moist soils were made by the

rapid chemical methods of analysis. The soils were extracted and analyzed the same day on which the samples were taken, thereby eliminating the fluctuations which may occur in soil-nitrogen relationships upon soil storage. In this manner a periodic measure of available nitrogen status of the soil without the interfering factors of plant growth and loss by leaching was secured. Fluctuations were investigated where gains and losses of nitrogen were indicated as the result of nitrification and seasonal changes. Studies were made of the nitrification of added nitrogen from ammonium nitrate, as well as of the original nitrogen in the soils; in both cases ample fertilization with phosphate and potash was given.

NITRIFICATION

Reviewing, briefly, recognized truths established by other investigators, it may be stated: When either ammoniacal or organic nitrogenous fertilizer is applied to a soil, the nitrogen thus added is gradually converted to the inorganic nitrate (or nitric) form. This process is known as nitrification. Conversely, when nitrate is reduced or changed to the gaseous oxides of nitrogen, or to the ammoniacal form, the process is known as denitrification. Soils vary individually in their capacities to support these changes.

Occurrence in Acid Soils:

Nitrification occurs readily in neutral soils. While nitrification is known to proceed in acid soils, it has often been assumed that the process is suppressed in such soils. From the standpoint of learning what happens to ammoniacal nitrogen when it is applied to an acid soil, it was considered desirable to make nitrification studies on such soils. Two acid soils were selected; one of these was a surface soil from Manoa Field 22 which had a pH of 5.8 and the other, a surface soil from Hamakua Field 27K with a pH of 5.5. Ammonium nitrate, supplying equal amounts of ammoniacal and nitrate nitrogen, was added to these soils.

Data obtained from these incubation experiments are submitted graphically in Figs. 1, 2, 3, and 4. The results indicate that active nitrification has occurred in these acid soils. It will be noted that, following the nitrification of the added nitrogen, very little ammoniacal nitrogen was found in any of the soils during the entire incubation period.

Time Required to Reduce the Ammoniacal Nitrogen Level:

During the process of oxidation of ammonia to nitrate, the ammoniacal nitrogen level is gradually reduced and nitrate tends to increase correspondingly as oxidation reaches completion. However, a lag may occur following the lowering of the ammonia level before the nitrate analysis is shown to increase, the degree of the lag depending, perhaps, on the speed with which the various steps of oxidation can be completed. Aside from considerations of its removal by microorganisms in processes other than nitrification, or of losses by chemical reaction, and since loss by leaching is not a factor in these experiments, any lowering of the ammoniacal nitrogen level in this uncropped soil may be assumed to indicate nitrification activity. This assumption has been supported by increases of the nitrate levels which follow the

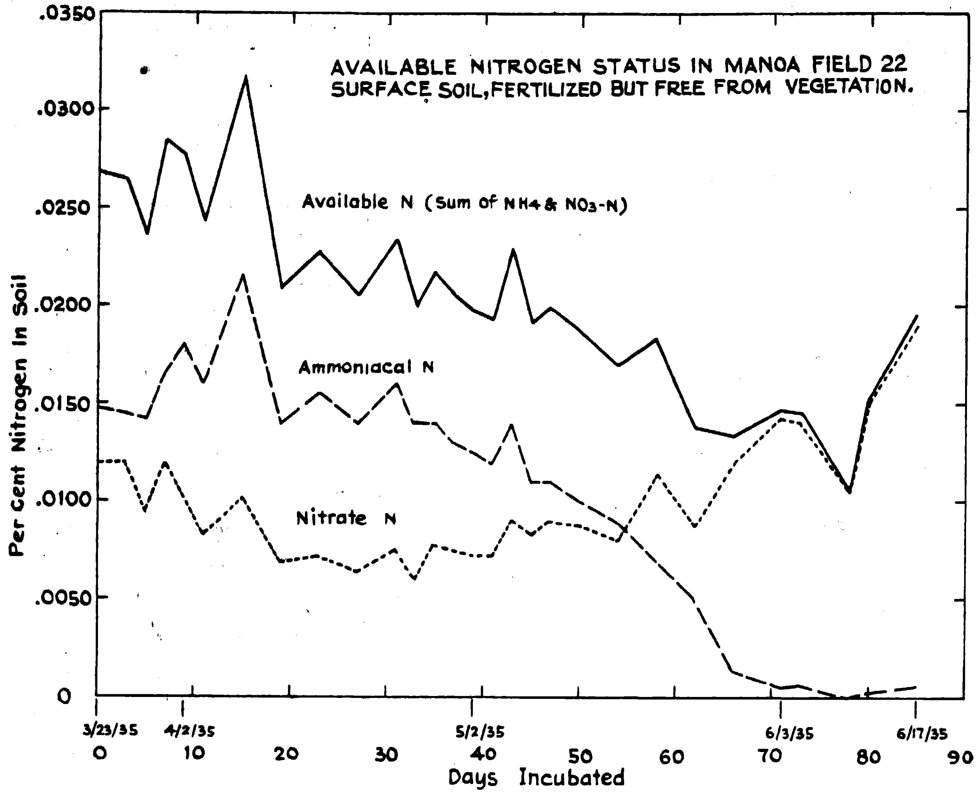
AVAILABLE NITROGEN STATUS IN MANOA FIELD 22
SURFACE SOIL, FERTILIZED BUT FREE FROM VEGETATION.
Available N (Sum of NH4 & NO3-N)
Ammoniacal N
Nitrate N
Per Cent Nitrogen in Soil
.0350
.0300
.0250
.0200
.0150
.0100
.0050
0
3/23/35
4/2/35
5/2/35
6/3/35
6/17/35
0
10
20
30
40
50
60
70
80
90
Days Incubated

Fig. 1

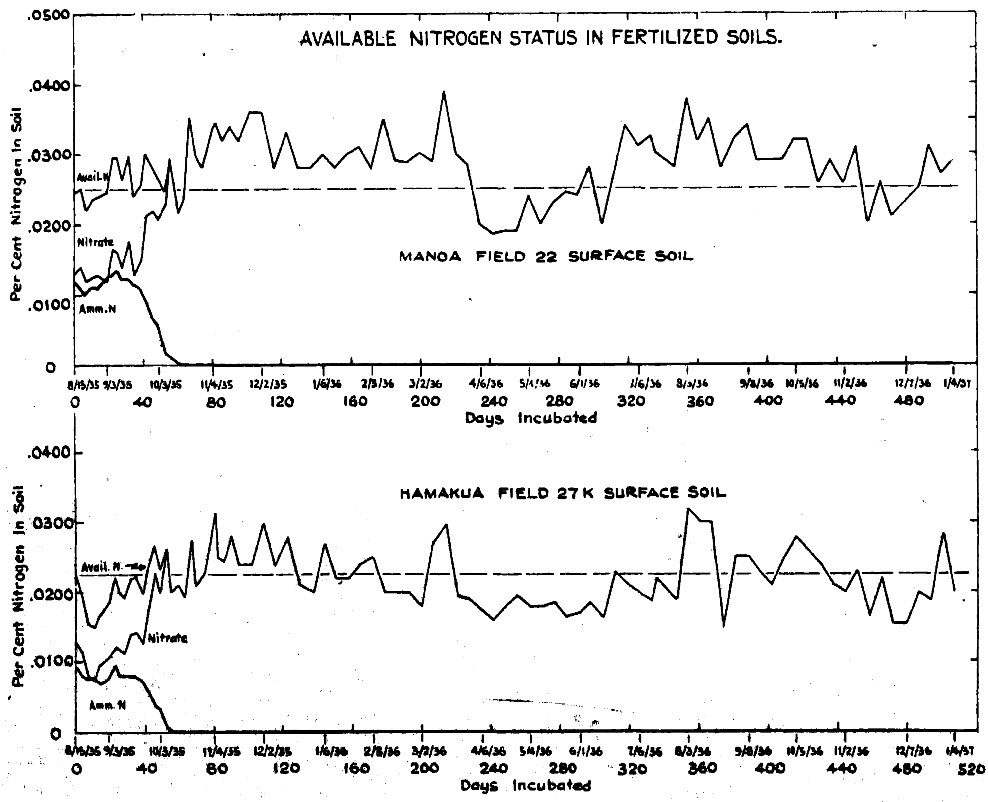
AVAILABLE NITROGEN STATUS IN FERTILIZED SOILS.
MANOA FIELD 22 SURFACE SOIL
Avail. N
Nitrate
Amm. N
Per Cent Nitrogen In Soil
.0500
.0400
.0300
.0200
.0100
0
Days Incubated
HAMAKUA FIELD 27 K SURFACE SOIL
Avail. N.
Nitrate
Amm. N
0
40
80
120
160
200
240
280
320
360
400
440
480
520

Fig. 2

depletion of ammonia. Therefore, for practical purposes, the time interval required to deplete ammoniacal nitrogen may be considered as the time required to nitrify the ammoniacal nitrogen which was added to the soil in the incubation pots under consideration.

In the initial (March) test with the Manoa soil (Fig. 1), a period of 78 days was required for the nitrification of the added ammoniacal nitrogen. The ammoniacal nitrogen content of the soil was 0.0148 per cent following the addition of 1.1 grams of nitrogen from ammonium nitrate (one-half of which is in the ammoniacal form) to each pot (4½ kilograms of soil). At the end of 78 days, the ammonia level in this soil had reached zero, as indicated by soil analysis. The second test with this soil (Fig. 2), receiving the same treatment, but started some 5 months later (in August), gave results which showed that nitrification required only 63 days. This same soil, without any nitrogen fertilization, required but 50 days for the depletion (Fig. 3) of its ammoniacal nitrogen when the initial level in the soil was 0.0015 per cent. Thus, it will be seen that the time required for nitrification may be variable for the same soil receiving the identical treatments, but started in different periods of the year (Figs. 1 and 2).

While it may not be comparable, for the reason that the soils are not identical, an incubation test started in May with another Manoa soil collected from an adjoining field showed an interval of only 35 days required to nitrify 0.75 gram of added ammoniacal nitrogen when the initial level was 0.0175 per cent ammoniacal nitrogen (Fig. 4).

A graph showing the status of the inorganic nitrogen throughout the incubation period for the Hamakua soil is presented in Fig. 2. Nitrification is found to occur readily in this soil under the environmental conditions found at the Makiki station. Started at the same time as the second test of the Manoa soil (in August), and receiving identical fertilizer treatments, a period of 56 days was required for the nitrification of its ammonia. This is one week less than the 63 days indicated for the Manoa soil incubation started at the same time.

Recovery: Loss and Gain of Available Nitrogen During Nitrification:

In many of our local investigations the disappearance of available nitrogen under field conditions is usually ascribed to loss through leaching and by uptake by the growing plants. Little consideration has been given to still another loss which is not accounted for by either leaching or plant absorption. The loss of nitrates following the incorporation of carbonaceous matter (especially molasses) in soils is often explained as being "immobilized" by microorganisms, with the inference that as their death and subsequent decomposition proceeds this nitrogen will become available again through nitrification. The quantitative studies by Lipman and his associates (20, 21) of the New Jersey tank experiments have indicated that loss of nitrogen from soil by means other than leaching and plant absorption may occur in considerable magnitude. Similar observations from field experiments have been made by English investigators. The results of many field experiments and lysimeter studies by American workers have been published which report findings of a corresponding nature.

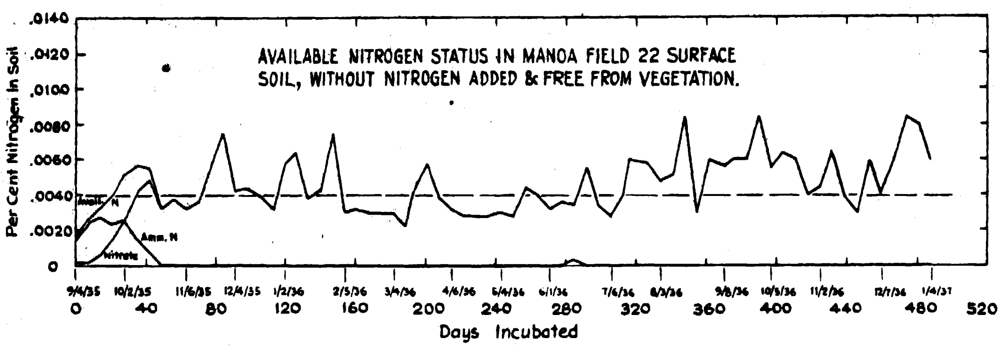

Fig. 3

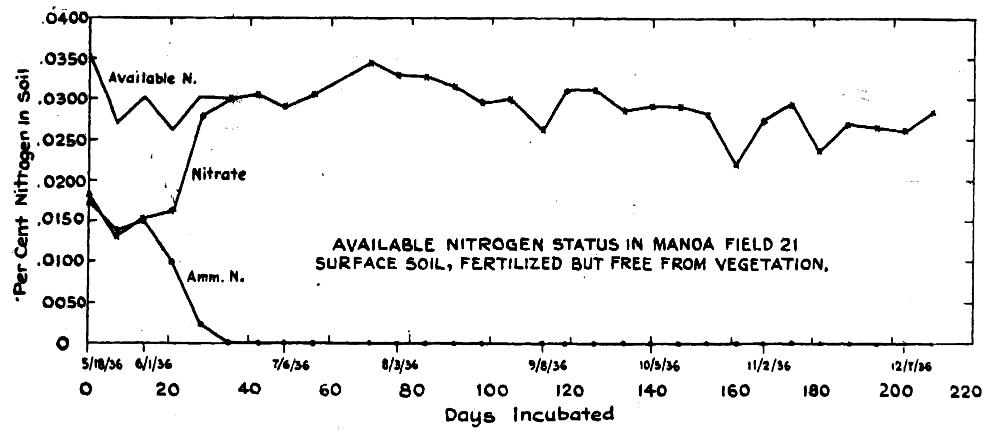

Fig. 4

A gradual loss of available nitrogen throughout the period of incubation in the first test with the uncropped Manoa soil is evident from an examination of the graphs in Fig. 1. Whether this nitrogen had disappeared from the soil or had been merely "tied up" with the organic fraction of the soil or in the microorganisms remains to be definitely established. Plants (Sudan grass) grown in this soil during the same period and with identical fertilization were harvested and analyzed. The nitrogen recovered in these plants, as shown by analyses, was not equal to the amount added. The difference between the theoretical amount which should have been found and that which was actually recovered at the period of their maximum plant-nitrogen content was approximately equal to that which was indicated as lost from the uncropped, similarly fertilized soil. While it was not shown that the loss of available nitrogen was permanent, its removal was at least established in that it was unavailable for plant growth during the period under test.

A study of Fig. 1 is of interest. It will be noted that during the first two weeks of incubation following nitrogen fertilization there was a slight denitrification which was accompanied with a corresponding rise in the ammonia level. From the fifteenth day on, there was a lowering of the nitrate level and a maintenance of this lowered level for an additional 3 weeks or until the eighth week of incubation; meanwhile the ammonia level was gradually declining. From the eighth week on, the drop in the ammonia was accompanied by a rise of the nitrate level. However, at

the end of this first test, on the eighty-fifth day of incubation, the sum of available nitrogen had never reached its level as found at the start of the experiment. Hence, it may be inferred that the nitrification of the added nitrogen fertilizer may not necessarily proceed quantitatively with 100 per cent efficiency.

In some respects the results obtained in the above test máy be compared with those reported by Eggleton (13) of the Jealott's Hill Agricultural Research Station, working with English soils. To study the distribution of nitrogen during the process of oxidation of ammonia to nitrate, nitrogen from sulfate of ammonia, from ammonium nitrate and from nitrate of soda was added to soils at the rate equivalent to 88 parts per million of ammoniacal nitrogen (0.0088 per cent). In addition to the treated soils, he had a control series. The soils were kept moist and aerated; the experiment ran for 5 weeks. Every weekday during this period two jars of soil were taken from each series and analyzed for ammonia, nitrate, nitrite, and albuminoid nitrogen. This study showed that the mean recovery in terms of ammoniacal plus nitrate nitrogen for the first week was only 91 per cent of the nitrogen originally added in the ammoniacal form. During the second week the recovery improved to 92.6 per cent; the third week it was 94.8 per cent and in the fourth week, 99 per cent. About 10 per cent of the nitrogen added directly as nitrate was not recoverable within the first two days. Subsequently the recovery averaged 100 per cent. However, recoveries were not as good during the last week of the experiment. Nitrite nitrogen was not found and albuminoid nitrogen was negligible. Three possible causes of this loss are advanced: incomplete extraction, immobilization by microorganisms and the existence of the nitrogen in a form escaping detection. The possibility of loss in the gaseous form through chemical reaction was considered but was discounted.

While a 100 per cent recovery of the added nitrogen was not obtained in the initial test with the Manoa acid soil, an examination of the Manoa and Hamakua soils in Fig. 2 will show that for the second set of experiments the available nitrogen status had attained the original levels after the twentieth and fortieth day of incubation, respectively. It will be noted that a loss of nitrogen had occurred during this initial period. For the other test with a Manoa soil started the following summer (Fig. 4), a loss of available nitrogen occurred which was not made up until about two months later. The recovery was temporary, as a decline immediately set in which persisted for approximately five months, the remaining period of the experiment.

Fluctuations Between Sampling Periods:

An examination of any of the nitrogen graphs in Figs. 1, 2, 3, and 4 will reveal considerable fluctuation in values between sampling periods. Thus, analysis of a sample obtained one day may not necessarily be the same for another sample taken several days later. However, it will be further seen that the fluctuations range within rather definite levels. In other words, the fluctuations do not occur, say, from a high to an extremely low level, or vice versa, between sampling periods of short duration. Thus, if certain levels are established, the available nitrogen status will probably fluctuate within the level attained at equilibrium. Therefore, in spite of the variable nature of the nitrogen value determined at the moment, it can be of

practical use if used in conjunction with its relative fertility level and a factor which will take care of the expected fluctuations between sampling. (Further discussion will be made later of such fertility levels.)

Seasonal Fluctuations:

Superimposed over the fluctuations that occur within short durations are those which occur over longer periods of time, or the seasonal changes. In discussing fluctuations of nitrate nitrogen, Russell (32) brings out the point that nitrogen-producing agencies are active in the spring and work throughout summer and autumn while the nitrogen-removal agencies are active in summer and winter; hence, nitrates in an arable cropped soil are highest in the spring, drop in summer, often rise in autumn and fall again in the winter. Recent studies with Indian soils by Sahasrabuddhe (33) have indicated regular fluctuations in nitrogen content from month to month, with the highest value generally during the cooler months (November-February). Eggleton (14) found seasonal fluctuations in the total nitrogen content of grassland soils. Studying the nitrogen cycle in grassland soils at Rothamsted, Richardson (31) noted no clear seasonal changes in available nitrogen of these soils, but of the easy mineralizable nitrogen, a maximum was found in early spring and this normally decreased in summer and increased again in winter.

Long-range fluctuations, suggesting the possibilities of seasonal changes in the available nitrogen content of the unfertilized Manoa soil, are apparent from an examination of the data shown in Fig. 3. Similar trends are also noted in the fertilized soil, Fig. 2. The nitrogen level rises in fall and winter, begins to drop in spring, remains low in early summer, then begins to rise significantly in early fall, with the higher levels persisting through winter.

Fertility Levels

The growth of many of our economic crops is dependent upon nutrients, either added to or originally present in the soil and which are in available forms or can readily become available. Such factors as varieties, climatic and environmental conditions and the presence and adequacy of other nutrient elements all tend to influence the requirement in a soil for any particular nutrient. However, in general, for sugar cane culture, where the amount of soil phosphate is shown by rapid chemical analysis to be less than 30 pounds per acre, the level is low and response to phosphate fertilization may be expected. Where analyses show quantities in excess of 100 pounds per acre, the level is high and response is not likely to occur. Intermediate values have also been established. Similarly, the levels for soil potash have also been established as determined by the rapid chemical method: less than 125 pounds as "low," and greater than 300 pounds per acre as "high."

In the interpretation of soil nitrogen data, establishment of similar soil fertility levels is approached on a different basis. In the determination of nitrogen by the rapid chemical method, the analysis indicates the amount of this nutrient *present at the moment only* and does not give any indication of the rate of further formation from the non-available fraction or of the total amount that may become available throughout the entire growth period of a crop. Hence, the interpretation of the data

from soil nitrogen analysis will not necessarily be to determine the adequacy of the soil supply to furnish the entire nitrogen needs of the crop, but rather to evaluate the amount which we can expect the soil to furnish at the moment.

While many of our sugar cane soils contain between 2,500 to 12,500 pounds of total nitrogen per acre-foot of soil, this nutrient is usually found as the factor limiting cane growth. The investigations of Kelley and Burgess have shown that while nitrification occurs in all of our soils, the formation of available nitrogen from the combined nitrogen in most of our soils is negligible. Later work by McGeorge is in agreement with these findings. Observations from pot experiments, with either Sudan grass or sugar cane growing in certain acid soils within the restricted areas of the containers, have indicated that very little nitrogen can be formed which will produce growth comparing favorably with the same soils to which nitrogen fertilizers have been added.

Due to the inability of the soil to supply an adequate amount of available nitrogen from its own total store of nitrogen, the needs of the crop are not supplied and hence the usual response to nitrogen fertilization is secured. As early as 1910, from the results of field experiments, Eckart (11) called the attention of the plantation managements to the great importance of nitrogen fertilization for sugar cane in Hawaii. He stated that all the different types of soil, even those of high total nitrogen content, would give increased returns from fertilizers containing a relatively large amount of readily active nitrogen, irrespective of conditions of large or small rainfall. The agreement is general today that a definite response to nitrogen fertilization for sugar cane is almost always secured, and the major problem becomes one of determining the optimum amount to be used. In general, yield increases from applications up to 150 pounds of nitrogen per acre have been considerable, while increases for applications in excess of 250 pounds have been small.

When the nitrogen found in the soil sample by rapid chemical analysis is reliably evaluated, the corrected amount may be given due consideration when determining how much nitrogen fertilizer to apply at the time. Such consideration was demonstrated in a recent test reported by Denison (10). At the start of the second ratoon crop of H 109 cane growing in a field at Kahuku Plantation Company, Denison found the soil to contain 188 pounds of available nitrogen by the rapid chemical method of analysis (without further evaluation as outlined later in the discussion). Because of this large indicated amount of available nitrogen, fertilization was deferred for 8 months at which time the soil analysis showed very little available nitrogen left and the cane plant began to show nitrogen deficiency symptoms. Fertilization was then made at the rate of 60 pounds of nitrogen per acre, an amount considerably lower than previously applied in this area, and this amount was all that the crop received from its nitrogen fertilizer. At the age of 15 months, when this crop was harvested, the yield was equal to or better than either of the two previous crops, despite the greatly lowered nitrogen fertilization. It may be inferred that the soil had significantly contributed a large share of its available nitrogen to this cane crop. The results of this demonstration were substantiated by an "amounts-of-nitrogen" test in the same locality in which amounts of nitrogen over 100 pounds per acre (which was the minimum used in this field test) failed to produce any gains in sugar.

The above citation must not be viewed as a claim that the cane plant can make satisfactory growth with deferred nitrogen fertilization only in a soil which is high in available nitrogen. It has been known that in several instances, good growth has proceeded even in soils that were low in available nitrogen at the start and where nitrogen fertilization was deferred for several months. It may be that in such instances, the formation of the available forms through ammonification and nitrification of the soil's own supply of total nitrogen had continued at a rate that was sufficient to supply the early requirement of the crop for this nutrient.

In many fields which are in continuous cultivation, the analytical data will show equilibrium values which indicate the lowest level which may be reached by available nitrogen in the soil. At this level the nitrogen which is made available from the total supply is balanced by the amounts absorbed by plants and removed by biological agencies or by leaching. The analyses of many soils which are sampled immediately after harvest have indicated a content of from a trace to about 25 pounds per acre, except that in certain of our wetter areas, 50 to 100 or more pounds per acre may be found.

The relation of nitrogen to plant growth, as determined by the Mitscherlich procedure and by a method of chemical soil analysis has been investigated by Nemec and Koppova (26). They developed a chemical method which appears to be comparable to the Experiment Station rapid method. Their method determines the nitrates obtained by water extraction of the soil and ammoniacal nitrogen by extraction with a 0.5 normal solution of sodium chloride. Nemec and Koppova working with European soils (Praha-Dejvice) found that the momentary combined nitrate and ammoniacal nitrogen content of a number of soils agreed well with the results obtained by the Mitscherlich pot tests. Their studies indicated that .0075 per cent of available nitrogen in the soil was the lower limit to which the combined nitrate and ammonia nitrogen content should sink for satisfactory growth.

A study was made of the results of 16 of our pot experiments picked at random from a series of Mitscherlich tests of soils, with Sudan grass as the indicator crop grown during one month. The relation of available nitrogen, determined by both the biological and chemical methods of analysis, to the yield of Sudan grass was investigated. Data from this study appear in Fig. 5, the soils being arranged from left to right in an ascending order of the yields which they produced without nitrogen fertilizer. In general, it appears that yields are related proportionally to the available nitrogen supply of the soil as determined by the two methods of analysis. However, exceptions are noted for several pots which showed low availability upon chemical analysis but produced larger crop yields. The same explanation of the rate of nitrogen formation as cited for the growth of sugar cane in the field may hold true for these exceptional pots. Thus the results of this study appear to indicate that where nitrogen availability is high at the start as indicated by R.C.M. soil analysis, the yields will be larger (providing that nitrogen alone is the limiting factor), The available nitrogen supply (by R.C.M.) of the soils studied ranged from 20 to 200 pounds per acre and the soils represent cane areas from the four islands, Oahu, Kauai, Maui, and Hawaii. Total nitrogen data of these soils are also included in Fig. 5.

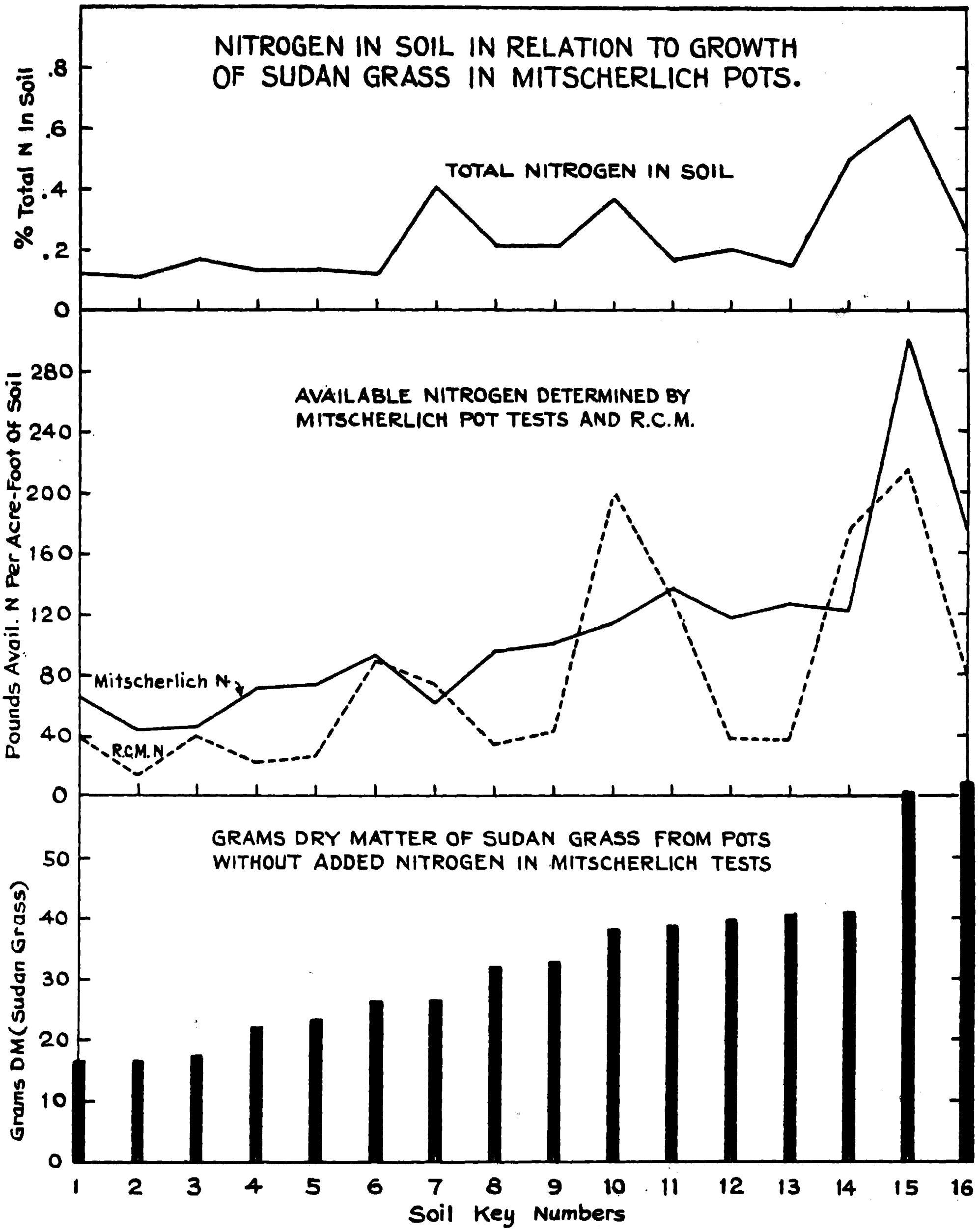

Fig. 5

It is suggested that in evaluating the R.C.M. soil nitrogen data, the levels of fertility be set as low, doubtful, medium, and high according to the following tabulation:

FERTILITY LEVELS FOR R.C.M. NITROGEN

Group	Per Cent	Pounds N per Acre-Foot of Soil
Low	—.0010	—25
Doubtful	.0010–.0020	25–50
Medium	.0020–.0040	50–100
High	+.0040	+100

When the results are within the *low* group, little significance may be attached to the amount of nitrogen present for immediate plant growth, for the reason that the values in this group may fluctuate from 0 to 25 pounds per acre. When the analytical result falls in the *doubtful* group, it may be considered as the "low" for most soils but for some soils it may have a real value. Some quantitative significance may be attached to the nitrogen in soils of the *medium* group. However, it is when the soils are in the *high* group that the nitrogen thus indicated is considered to be an immediate consequence in plant growth. "High" in this case is not to be interpreted as an indication that the soil is able to supply all the nitrogen for the entire crop requirement; it is only a qualification of the amount present at the moment. The ability of the soil to furnish all the nitrogen required is more likely to be dependent upon the rate of formation of this available form and may be independent of the amount found at the moment, which is only a measure of the accumulation at the moment of analysis.

A study of the relationship between cane yields in pot growth and soil nitrogen is presented in Table I.

TABLE I

Relation of available nitrogen in soil (original and added) to growth of sugar cane in pots.

Soil No.	Original N lbs.	Grams Dry Matter* Produced from Added Nitrogen of None	100 lbs.	200 lbs.
1	24	54	106	128
2	49	56	109	118
3	88	71	116	121
4	109	67	101	131
5	210	90	131	146
6	300	130	161	162

* Stems, leaves, and roots.

Mixtures of two Makiki soils were made so that the resultant combinations contained different amounts of available nitrogen, from 24 to 300 pounds per acre-foot of soil as indicated by rapid chemical analyses. Three sets of pots containing these soils were obtained, one of these was left without nitrogen fertilizer additions while to the other two sets additional nitrogen, at the rate of 100 and 200 pounds per acre respectively, was added. Phosphate and potash were supplied in ample amounts and the pots were planted to H 109 cane shoots. After growing until all pots showed definite signs of nitrogen deficiency the pots were harvested and the yields of dry matter were obtained. The data appear to indicate that yields were alike for each respective series where the soils showed initial analyses below approximately 100 pounds nitrogen per acre, but when they had more than 100 pounds, the yields were increased correspondingly. Hence the results support the 100-pound level from our R.C.M. analysis as being a critical amount significant for growth requirements.

Thus, two levels can be established—low and high—to which a significance of inadequacy or adequacy of the amount determined by R.C.M. analysis may be attached. These levels form the qualitative test of the soil's available nitrogen supply. Where a quantitative estimate is desired, so that an allowance can be made in the fertilizer schedule for the amount determined by the analysis, a factor of safety

should be applied which will take into consideration the sampling fluctuations which occur. Such a factor has been estimated from data at hand and is arbitrarily set at 50 per cent or one-half of the amount determined when such amount is greater than 100 pounds per acre-foot. This factor may also be applied to the results in the medium group if several consecutive samples show results that fall within the percentage limits for this group.

Thus in evaluating the R.C.M. soil nitrogen data, we would proceed as follows: (1) classify the soil qualitatively as low, (doubtful, medium,) or high; and (2) if the analytical results place the soil in the "low" group, disregard them quantitatively, but if the "high" group is indicated, then multiply the indicated pounds per acre-foot by one-half to determine the corrected amount for which a nitrogen allowance may be made in the subsequent nitrogen fertilization.

The practical application of this procedure may be illustrated by the use of data cited in the Kahuku test. The initial analysis showing the presence of 188 pounds of nitrogen per acre-foot of soil, places this soil in the "high" group for nitrogen. If this nitrogen is to be given consideration in the fertilizer schedule, then one-half of 188 or 94 pounds may be deducted from the regular amount to be applied. As stated in the earlier part of this discussion, the usual nitrogen application for sugar cane crops is between 150 to 250 pounds. The minimum requirement of nitrogen to produce an economic crop of cane remains to be determined. This minimum will no doubt depend upon the variety, soil, climatic and environmental conditions, and the adequacy of other nutrients. Assuming that the minimum requirement for the crop under consideration is 200 pounds per acre, then 200 minus 94 or 106 pounds of nitrogen would need to be added to make up the balance required. The actual addition of 60 pounds of nitrogen per acre for the Kahuku crop was found to produce a satisfactory yield, and the amounts-of-nitrogen test for this area showed that quantities over 100 pounds failed to produce further gains in sugar.

Plant Growth Studies

In the preceding discussion the available nitrogen status in a soil free from plant growth has been considered. The next concern is with the available nitrogen level in the soil as influenced by plant growth and more especially the relationships between nitrogen fertilization and plant growth, particularly the rate of absorption, the recovery of the nutrient in the harvested material, and the rate of plant growth.

The experiments were conducted with both Sudan grass and sugar cane grown in Mitscherlich pots, in an acid soil from Manoa. The results obtained from both crops were comparable and lead to the same general conclusions. Hence the data and discussion presented here will deal mainly with the sugar cane series.

Experimental:

Data concerning the available nitrogen status of a soil under plant growth, and the absorption of nitrogen by sugar cane were obtained from several experiments in which H 109 cane shoots were planted in Mitscherlich pots. The details of one of these experiments will be described below while the others will be presented under the respective sub-phases that follow. Phosphate and potash were added to a Manoa

(Field 21) surface soil at the rate of 9.0 grams P_2O_5 and 1.5 grams K_2O per 4½ kilograms of air-dry soil. Nitrogen at the rate of 1.5 grams N from ammonium nitrate solution was added to each pot. Soil and fertilizer ingredients were thoroughly mixed before potting. Two pregerminated shoots from one-eye cuttings of seed pieces were planted in each pot. These shoots were germinated in sand boxes and grew for one month before transplanting. Irrigation was applied regularly in amounts ample for plant growth. Check pots fertilized but without growing plants were also started, the data of which were previously reported in Fig. 4 of this report.

At periodic intervals, soil samples were obtained for R.C.M. analysis of available nitrogen, and plants were harvested for yields of dry matter and total nitrogen determinations. The sampling followed a procedure of taking one or two pots (at random), harvesting the cane plants, separating the roots from the soil by a careful process of picking and screening, and thereafter thoroughly mixing the soil. A portion of this mixed soil was then obtained for the immediate determination of its available nitrogen. The plant material was oven-dried, weighed, and prepared for total nitrogen determination. The experiment was continued for 7 months. Data from this experiment appear graphically in Figs. 6, 7, 12, and 14.

Available Nitrogen Levels in Soil Supporting Cane Growth:

Due to the additional factor of absorption by the crop, the nitrogen status in a soil in which plants are growing is often different from that existing in an uncropped soil. In the presence of active plant growth, the forces concerned with nitrogen removal may dominate those concerned with its accumulation and hence the nitrogen level is generally low. It has been shown by Albrecht (1) from a study of Missouri soils under different crops and treatments that the crop is a significant factor in removing nitrates from the soil and that the exhaustion of this nutrient is closely similar for the same soil whether the crop is grass, corn, or wheat. Similarly it has been found by Richardson (31) and Eggleton (12) that the amount of nitrate nitrogen in grassland soils is usually low under good growing conditions.

Richardson studying grassland soils at Rothamsted pointed out that neither ammonia nor nitrate was normally accumulated to any extent in these soils and in general the ammonia level was above that of the nitrate. He found that ammonia added to these soils disappeared in the short period of a few weeks in winter or a few days in late spring. Nitrates were found only in small amounts. Added nitrates disappeared as rapidly as ammonia. It was further indicated that ammonia nitrogen was as readily removed from an acid soil as was nitrate when herbage was present but that it remained if the herbage was removed.

The retention of nitrates by Ewa soils under field conditions in which H 109 cane was growing was studied by Stewart and Hansson (34). Nitrogen was added to the soil in two applications of 100 pounds each, to cane which was 6 months old at the start of the experiment. Analytical data indicated that the nitrate content of the soil had been reduced to the level prevailing before fertilization within 8 to 12 weeks after the first fertilization and a still shorter period after the second fertilization. From soil nitrogen and moisture data it was concluded by these investigators that the rapid disappearance of nitrates was caused by the extraction of this nutrient through the growth of the cane crop.

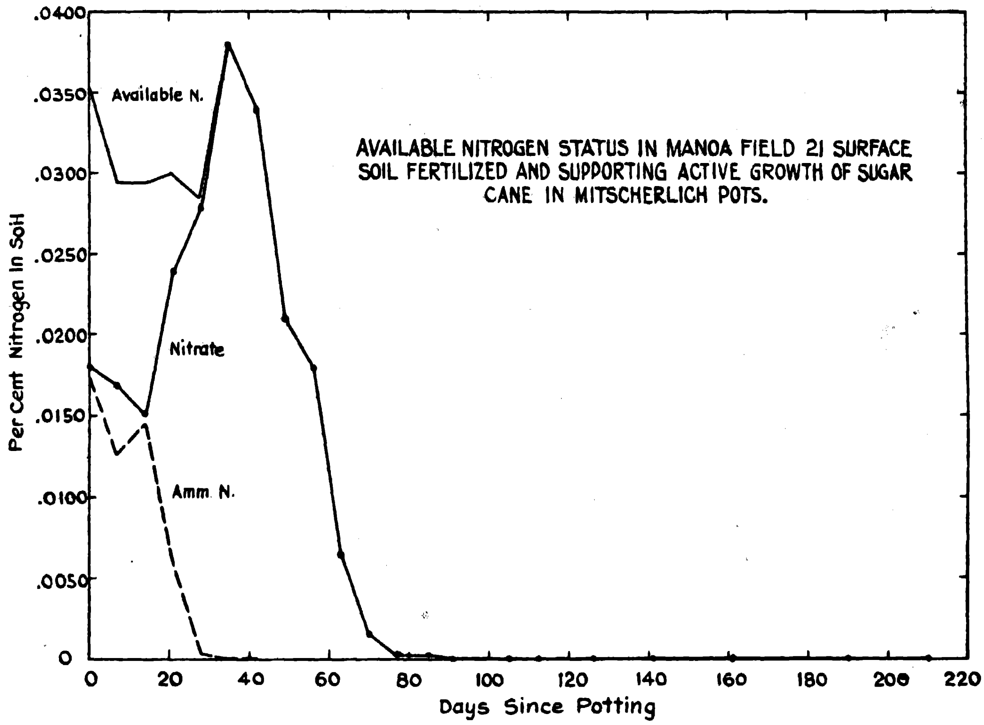

Fig. 6

The available nitrogen data for the soil supporting active growth of sugar cane in pots of the experiment conducted for this study are presented graphically in Fig. 6. The original air-dry soil with phosphate and potash added showed an analysis of .0010 per cent available nitrogen. The addition of the nitrogen fertilizer brought this value to .0355 per cent. It will be noted that starting with the level of .0355 per cent, the percentage of nitrogen decreased during the growth of the cane plants until, at approximately 90 days or about 13 weeks following transplanting of the shoots, only a trace or practically no nitrogen remained in the soil as determined by R.C.M. analysis. The available nitrogen status of the same soil receiving identical fertilization but free from vegetation may be obtained in Fig. 4.

The nitrogen level continued to be low following soil depletion and during the subsequent period of active growth. This result is consistent with the findings of others cited above for grassland and other soils under crops. It is apparent that if the root mass is confined within a restricted area as found under the pot conditions, depletion of nitrogen may be carried to the point where practically no accumulation can occur and hence the extremely low level is constant.

Albrecht (1) in discussing the determination of available nitrogen in the soil under an equilibrium status points out that such a measure is not an indication of the quantity of nitrogen removed or produced; rather, it is the lowest level which represents a balance of the forces of accumulation against removal by cropping, microorganisms or other agencies, and leaching. He found the equilibrium values for grass and wheat to be between 6 to 12 pounds. Stewart and Hansson (34) reported in one instance 6 to 15 pounds per acre for Ewa soils under H 109 cane, and in the present pot study the data indicate that the level may be as low as nil. In an experi-

ment (6) recently completed to study the status of available nutrients during the active cropping of sugar cane in a plantation field it was found that the equilibrium level of nitrogen in the soil at the start of the crop averaged 25 pounds. With each fertilization the level was significantly raised and rapidly lowered following a short interval. The equilibrium level of nitrogen in the soil when the cane was mature was not much higher than that at the start.

Rates of Absorption:

As stated previously the nature of the pot experiment was such that loss by leaching need not be considered as a factor in this study. Excepting its removal by immobilization in microorganisms or loss through gaseous evolution, the nitrogen indicated by R.C.M. analysis as removed from the soil was assumed to be absorbed

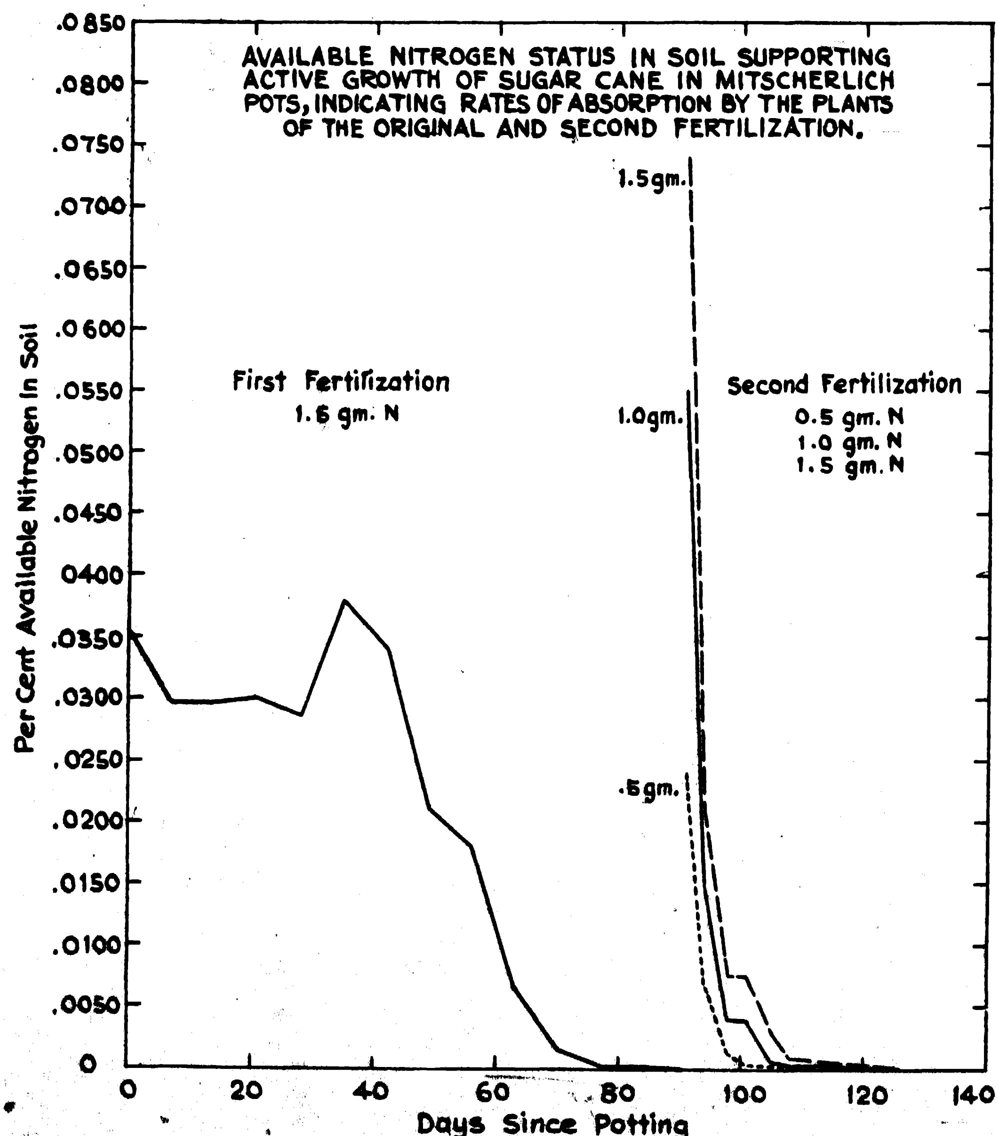

Fig. 7

by the growing plants. Hence the rate with which available nitrogen disappears from the soil may be employed in this study to indicate the rate with which the cane plant can absorb its nitrogen. It has been shown by Richardson that grass can absorb nitrogen at various rates depending on the time of application and the age of the crop. Stewart and Hansson found that under field conditions, H 109 cane was able to absorb the second application of nitrogen much quicker than the first.

The rates with which the cane growing in pots can absorb nitrogen may be obtained from a study of Figs. 6 and 7. It will be noted that nitrogen absorption is very slow at the start following transplanting of the month-old shoots. After the first 4 weeks, however, the soil showed a rapid disappearance of its available nitrogen, indicating an absorption by the growing cane at an accelerated rate. From a consideration of the comparative root system of the shoots at planting with that which had developed at about 4 or 6 weeks following transplanting, it is reasonable to conclude that with the enlarged root area an enhanced rate of absorption should occur. This should account for the increased rate of depletion that is noted in the soil following this period.

Effect of Age Upon the Rate of Absorption:

The original pot experiment was modified for a study of the rate of absorption during the stage of growth when the root system was enlarged and fully developed. Following the depletion of the first application of 1.5 grams nitrogen, pots from this experiment were divided into three series, and refertilized at the rate of ½, 1, and 1½ grams of nitrogen from ammonium nitrate solution applied to the surface. It was found by soil analysis that this second and later fertilization was removed from the soil within a period of about 6 weeks in contrast to its depletion from the soil with younger cane at about 13 weeks. Soil data comparing the disappearance of nitrogen in the soil following the original fertilization and the subsequent applications are presented in Fig. 7.

Additional data are presented in Fig. 8 which illustrates the quicker rate of absorption of nitrogen from somewhat later applications than those given during the first few weeks following planting. The results are from an experiment wherein a total of 1.5 grams of nitrogen was applied in three applications of ½ gram each in the following manner. The first increment was applied at the start to all series; for the subsequent increments: to Series 1, as soon as the soil analysis showed depletion of nitrogen; to Series 2, one week after the soil was depleted of nitrogen; and to Series 3, when the plants showed definite signs of yellowing. This procedure was followed until the total of 1.5 grams of nitrogen had been added. The data show that the nitrogen is more rapidly removed from the soil in the subsequent applications than in the initial application. A chart comparing the removal in Series 1 with the removal when the nitrogen was added as a single application is presented in Fig. 9.

Effect of Time of Application on the Rate of Absorption with Respect to Age:

In the preceding paragraphs the rate of absorption as affected by the age of the plant was discussed. The data were obtained under conditions of plant growth where nitrogen was applied to the soil at the start of the experiment. Data relevant

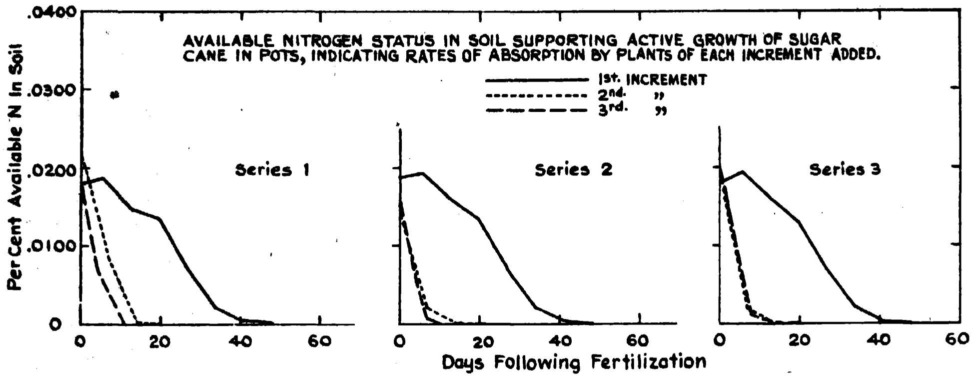

Fig. 8

to the rate of absorption as affected by the time of application are presented in the following discussion. Two pregerminated shoots of H 109 cane (age one month) were transplanted to each Mitscherlich pot which had been fertilized with sufficient phosphate and potash. Nitrogen in applications of 1.5 grams per pot was applied at variable intervals following planting. Soil samples were taken at weekly intervals for the determination of available nitrogen. The results of this experiment appear in Table II and Fig. 10.

TABLE II

Days required to effect complete removal of added nitrogen from soil growing H 109 cane (2 plants) in Mitscherlich pots. Application of 1.5 grams nitrogen, equivalent to 426 pounds N per acre.

Treatment	Days required for removal of nitrogen applied
NPK at planting	84
PK at planting, N at 21 days	63
PK at planting, N at 42 days	71
PK at planting, N at 56 days	64
PK at planting, N at 84 days	63

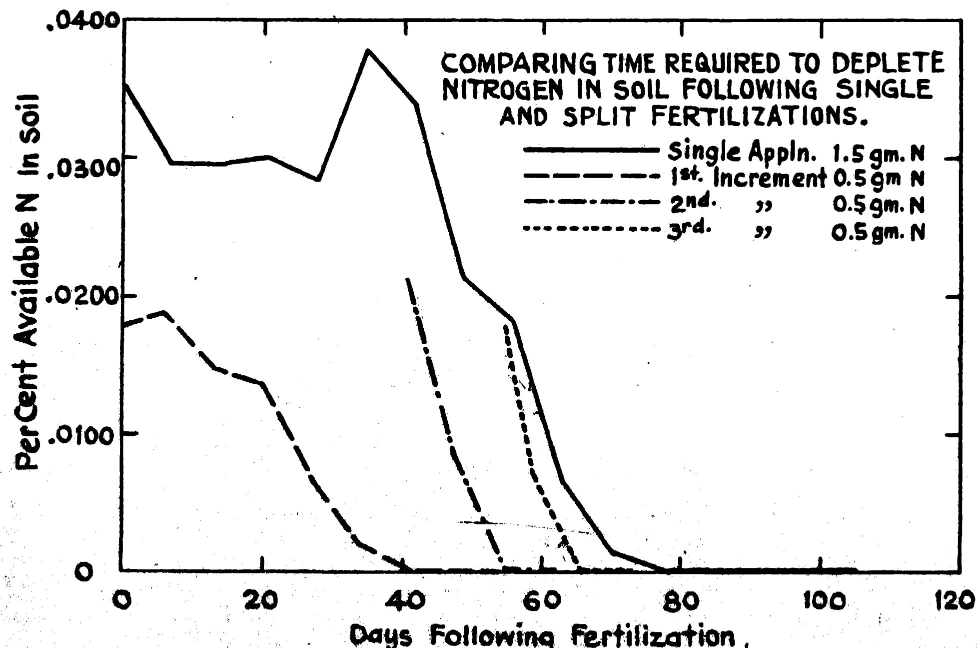

Fig. 9

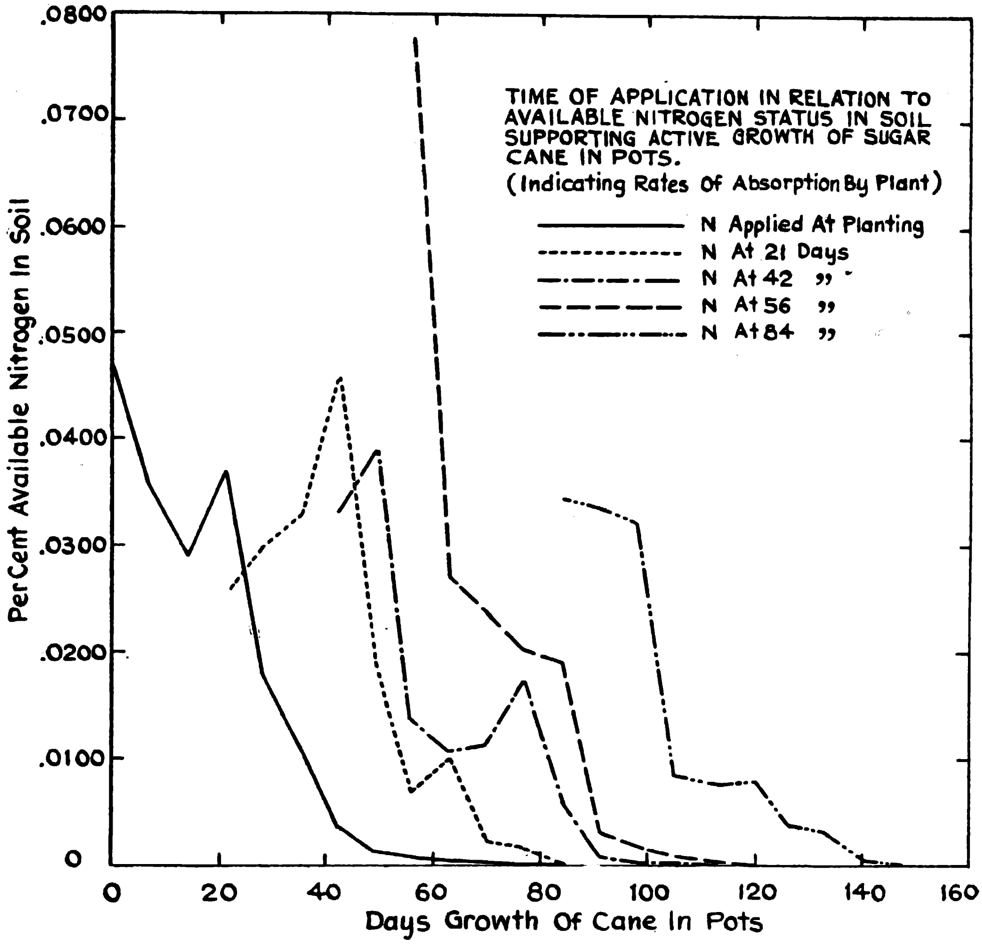
TIME OF APPLICATION IN RELATION TO AVAILABLE NITROGEN STATUS IN SOIL SUPPORTING ACTIVE GROWTH OF SUGAR CANE IN POTS.
(Indicating Rates Of Absorption By Plant)
N Applied At Planting
N At 21 Days
N At 42 "
N At 56 "
N At 84 "
Per Cent Available Nitrogen In Soil
.0800
.0700
.0600
.0500
.0400
.0300
.0200
.0100
0
0
20
40
60
80
100
120
140
160
Days Growth Of Cane In Pots

Fig. 10

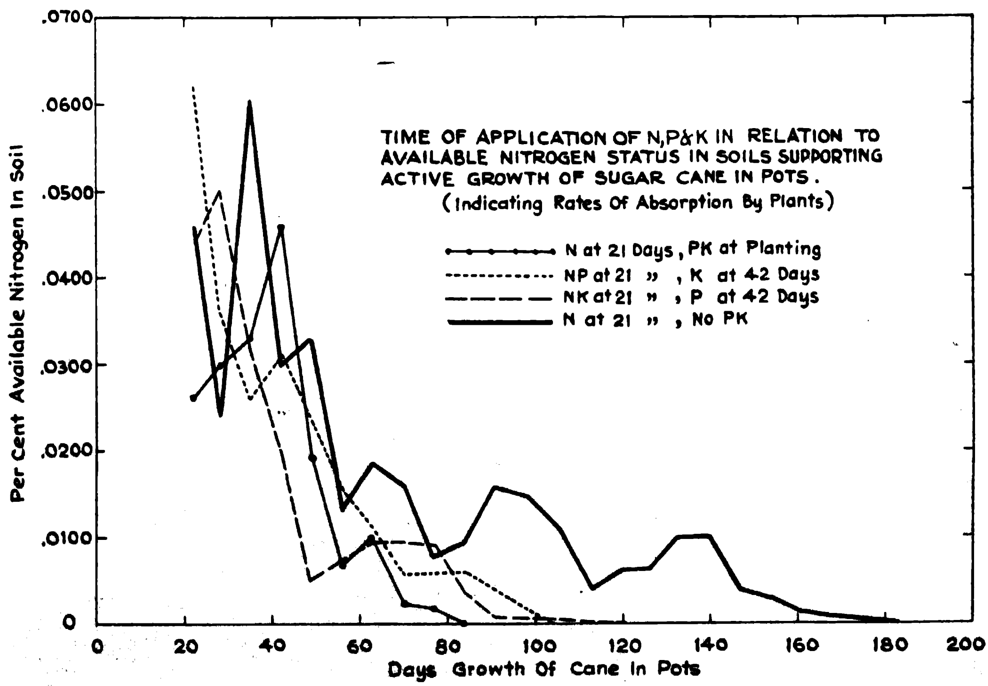
TIME OF APPLICATION OF N,P&K IN RELATION TO AVAILABLE NITROGEN STATUS IN SOILS SUPPORTING ACTIVE GROWTH OF SUGAR CANE IN POTS.
(Indicating Rates Of Absorption By Plants)
N at 21 Days, PK at Planting
NP at 21 " , K at 42 Days
NK at 21 " , P at 42 Days
N at 21 " , No PK
Per Cent Available Nitrogen In Soil
.0700
.0600
.0500
.0400
.0300
.0200
.0100
0
0
20
40
60
80
100
120
140
160
180
200
Days Growth Of Cane In Pots

Fig. 11

Data indicate that a shorter period is required for nitrogen removal after the plants have grown for a while, than when nitrogen was applied at the start. This is to be expected from the results of the preceding study. During the early period when only slight root development had taken place, very little absorption is to be expected. Evans (15) in a recent study on the effect of the root system on the absorption of nutrients by White Tanna cane reports that absorption is affected by the age and size of the root system, and also by the environmental conditions surrounding the roots.

Effect of Other Nutrients on the Rate of Nitrogen Absorption:

The effect of applications of N, P, and K at different intervals of time on the rate of nitrogen absorption by a growing crop was investigated in a pot experiment where these factors were considered. The Manoa soil used in this experiment contained 600 pounds phosphate as P_2O_5 per acre by rapid chemical analysis, an amount usually considered to be ample for crop growth under field conditions. Available potash was low in this soil. The plan of treatments and the results of this experiment are presented in Table III and Fig. 11.

TABLE III

Days required to effect complete removal of added nitrogen in soil supporting growth of H 109 cane in Mitscherlich pots. Applications of 1.5 grams N, 9.0 grams P_2O_5 and 1.5 grams K_2O at different intervals.

Treatment	Days required for removal after fertilization	Grams dry matter produced: Stalks and Tops	Trash	Total Aerial
At planting, N, P, K	84	156	75	231
At 21 days, N; at planting, PK	63	173	80	253
At 21 days, NK; at 42 days, P	99	176	69	245
At 21 days, NK; at 56 days, P	99	186	49	235
At 21 days, NP; at 42 days, K	84	185	64	249
At 21 days, NP; at 56 days, K	84	198	72	270
At 21 days, N; at 42 days, PK	99	161	67	228
At 21 days, N; at 56 days, PK	99	158	66	224
At 21 days, N only; no PK	161	50	33	83

Data appear to indicate that in addition to the time of nitrogen application, the time of addition of phosphate and potash exerted an influence over the rate of nitrogen uptake by the cane plant as indicated by soil analysis. In Fig. 11 the rates of nitrogen removal under 4 treatments of this test are compared. Nitrogen was applied to these 4 treatments at 21 days, while phosphate and potash were added either at the start, at 21 days or at 42 days. It will be observed in Fig. 11 that while the soil nitrogen was reduced to a low level in the 4 treatments at the end of the seventh week following nitrogen fertilization, a reduction to a zero level would be affected by the time of applying the phosphate and potash. While available phosphate was high in the soil, it appears that this nutrient added from fertilizer exerted the greater influence in the removal of N from the soil. Omission of phosphate and potash from fertilization resulted in the longest interval required for final depletion of nitrogen in the soil.

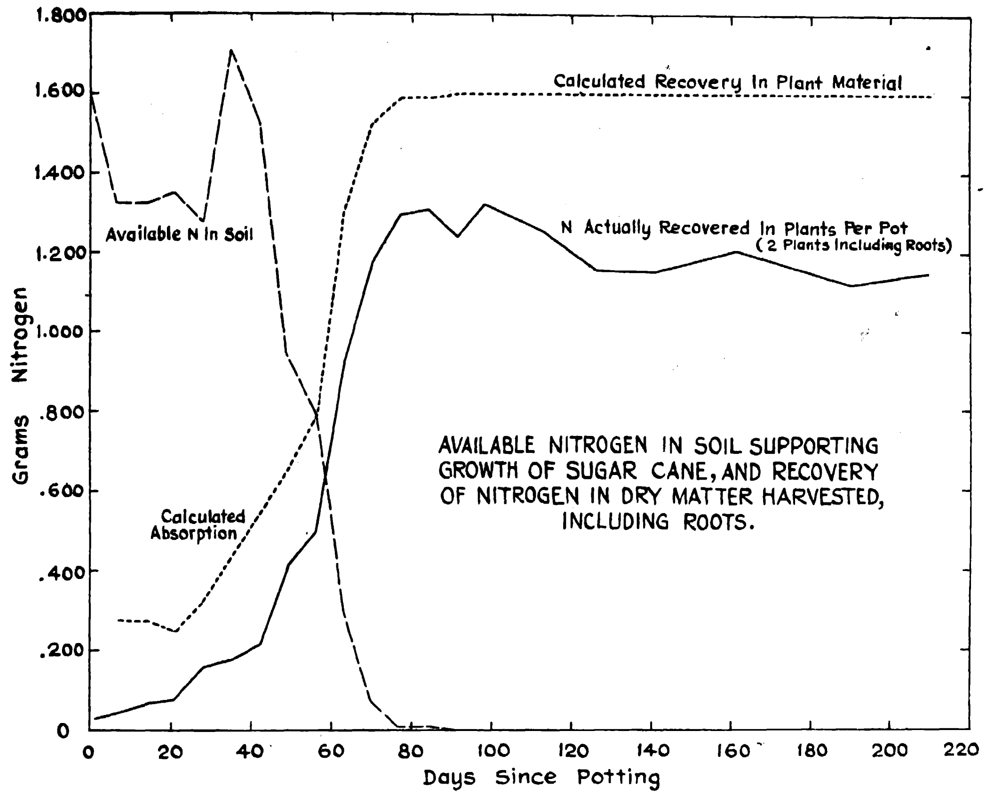
Calculated Recovery In Plant Material
Available N In Soil
N Actually Recovered In Plants Per Pot
(2 Plants Including Roots)
Calculated Absorption
AVAILABLE NITROGEN IN SOIL SUPPORTING GROWTH OF SUGAR CANE, AND RECOVERY OF NITROGEN IN DRY MATTER HARVESTED, INCLUDING ROOTS.
Grams Nitrogen
Days Since Potting

Fig. 12

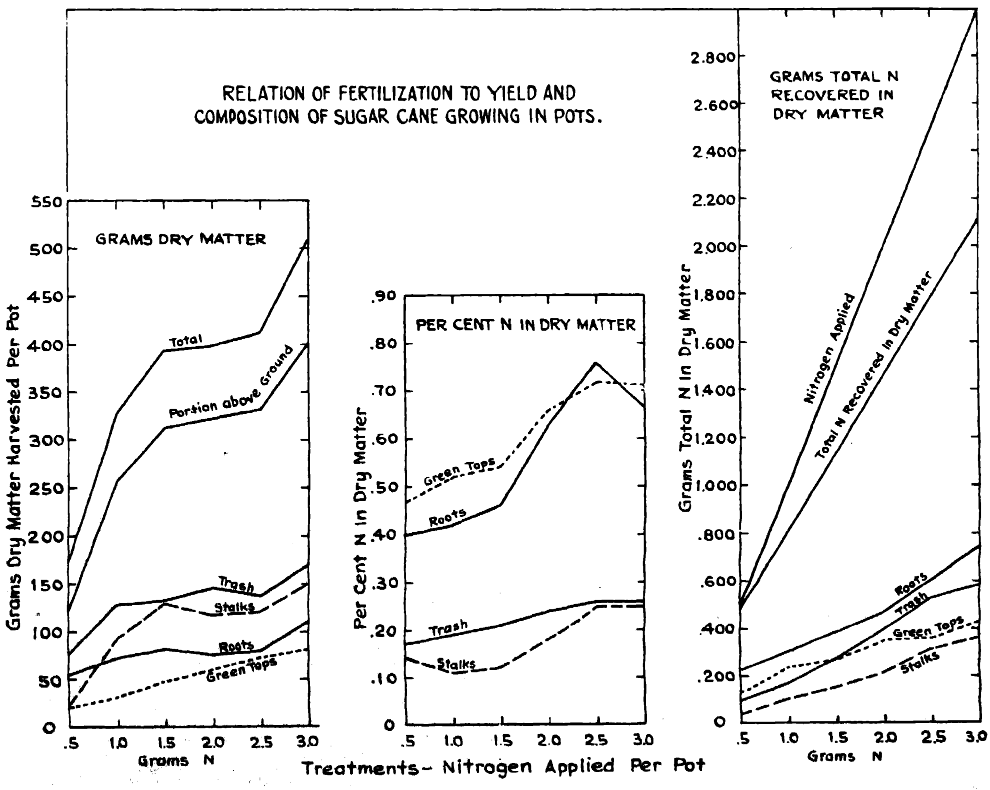
RELATION OF FERTILIZATION TO YIELD AND COMPOSITION OF SUGAR CANE GROWING IN POTS.
GRAMS DRY MATTER
Total
Portion above Ground
Trash
Stalks
Roots
Green Tops
Grams Dry Matter Harvested Per Pot
Grams N
PER CENT N IN DRY MATTER
Green Tops
Roots
Trash
Stalks
Per Cent N In Dry Matter
Treatments- Nitrogen Applied Per Pot
GRAMS TOTAL N RECOVERED IN DRY MATTER
Nitrogen Applied
Total N Recovered in Dry Matter
Roots
Trash
Green Tops
Stalks
Grams Total N In Dry Matter
Grams N

Fig. 13

Recovery of Nitrogen in Plant Material:

In the pot experiment with sugar cane previously described in this report and for which soil data were presented, plant material was harvested concurrently with soil sampling. Hence an analysis of the dry matter produced will show whether the nitrogen indicated by soil analysis to have been removed was actually absorbed by the plant.

The available nitrogen status of the soil during plant growth and the analytical data for total nitrogen in plant material harvested periodically during concurrent instances appear graphically in Fig. 12. The results appear to indicate that as the available nitrogen level in the soil declined the nitrogen recovered in the plant material increased. When the soil reached its initial lowest point of depletion, the nitrogen recovered in the cane sample was at its maximum. The rate of absorption as indicated by soil analysis, paralleled that indicated for the accumulation in the plant tissues. Nitrogen appears to be absorbed at a slow rate from the beginning to the fourth week. Thereafter a rapid accumulation is noted, ending on the thirteenth week, but after this time the amount of nitrogen contained in the plants (including roots) did not increase. A decrease is noted between the fifteenth and eighteenth week, but thereafter the amount recovered appears practically constant.

The Effect of Nitrogen Fertilization on the Yield and Composition of the Cane Plant:

The preceding discussion has been concerned with the available nitrogen status of a soil under conditions of plant growth, and has dealt with the removal of this nutrient from the soil and its absorption into the tissues of the sugar cane plant. In this next discussion, the relationship of nitrogen fertilization to the yield and to the composition of this yield is considered. Pot experiments with H 109 cane were conducted using Manoa soil fertilized with phosphate and potash. Nitrogen was applied in the following amounts: ½, 1, 1½, 2, 2½, and 3 grams per pot for two pregerminated cane shoots. The plants were grown for 210 days and then harvested. The yields of dry matter including roots were obtained and determinations of total nitrogen in the plant material were made. The results of this study appear in Fig. 13, the data representing the average of two pots of each treatment.

Yield—The total yield is found to increase with the amount of nitrogen applied, as is to be expected. The harvested material has been segregated into trash (dead leaves), millable stalks, green tops, and roots.

Percentage of nitrogen in dry matter—Not only is the differential fertilization reflected in the growth of the sugar cane but it is also found to affect the percentage composition of nitrogen in the dry matter of the plants. With increases in nitrogen fertilization, the concentration of this nutrient is increased in all sections of the cane plant (Fig. 13), the percentage composition being greatest in the roots and green tops.

Nitrogen recovered in dry matter—Loss of nitrogen—The analytical results showing the total nitrogen in the plants harvested from the differentially fertilized pots also appear in Fig. 13. The amounts of nitrogen contained in the different parts of the plant are shown, together with the total amount recovered in all sections

including the roots. It will be seen that a considerable portion of the nitrogen was found in the roots and trash. About 20 per cent of the amount added or 30 per cent of the total nitrogen recovered was found in the green tops.

The relationship which the amount of nitrogen recovered in the dry matter bears to the quantity applied offers an interesting study. Data in Fig. 13 indicate that the amount recovered is not equal to that which was applied. It appears that approximately only 70 per cent of the nitrogen applied is recovered in the plant tissues. The reason for this apparent loss is not definite. The experiments which have been completed thus far have been designed to determine whether there is any loss of nitrogen either from the soil or plants, rather than to seek an explanation for this occurrence.

In a previous preliminary experiment with Sudan grass, data were secured which appear to indicate that during the early period of growth and coincident with the removal of nitrogen from the soil, there was a loss of the available form of this nutrient from the soil. A considerable loss of nitrogen from the plant was found to occur while the Sudan grass plants were flowering and forming seed. The amount of nitrogen recovered at maturity was approximately only two-thirds of that recovered at the period when the nitrogen content was the highest; nitrogen at the forty-fifth day of growth averaged about 950 milligrams, while that found at harvest at 85 days was about 625 milligrams.

Referring again to Fig. 12 it will be seen that even at the start of the experiment there is an apparent discrepancy between the amount recovered in the harvested cane and that calculated to have been removed from the soil. The theoretical absorption was calculated from soil data by subtracting the nitrogen determined at each period from the original analysis. The differences represent the amount theoretically absorbed. The deficient amount appears to be constant up to the period of maximum uptake which came at around 90 days. Whether this initial deficiency represents nitrogen immobilized in the organic fraction of the soil or nitrogen lost from the soil as elemental nitrogen through reduction processes remains problematical. The limitation of the scope of the experiment and the data obtained do not offer a conclusion or solution. Following the period of maximum concentration in the cane plant as evidenced in Fig. 12, it will be noted that there is a drop from the ninety-eighth to the one hundred and twentieth day and that thereafter the nitrogen remains practically constant. The maximum concentration averages about 1300 milligrams while that at the later stages of growth from the one hundred and twentieth day on, averages approximately 1150 milligrams or a difference between maximum and minimum of 150 milligrams per pot of two plants, which the data suggest as being lost from the plant. In the case of Sudan grass, the loss was much greater, due perhaps to the growth processes concerned with its seed-formation stage. In the experiment with cane, the tasseling or flowering stage of growth was not reached. It has been shown by other investigators that during the tasseling stage of the sugar cane there is movement and relocation of the nutrients in the plant.

The possibility of considerable loss of nitrogen during the processes of nitrate reduction as a feature of nitrogen metabolism of plants has been advanced by Pearsall and Billimoria (27). The loss of nitrogen in its elemental form as free nitrogen from plant tissues as a result of chemical interaction has been studied by these Eng-

lish investigators. The chemical theory advanced is similar to that obtaining in the Van Slyke method of determining amino nitrogen whereby nitrous acid if present in the acid plant tissues may react with monoamino nitrogen to give elemental nitrogen.

The rate of absorption did not appear to affect the recovery of the nitrogen found in the plants during the period of maximum plant concentration. Thus, whether the nitrogen was applied at the start with its consequent longer period of absorption, or applied in split portions with its quicker and shorter period of uptake, the amounts of nitrogen found in the plants were practically alike in all treatments. This is apparent in studying the results of the experiments in which nitrogen was supplied as single or split applications. The amounts of nitrogen theoretically recoverable for each experiment include the amount originally present in the soil, the amount found in the seed pieces, and the amount added as fertilizer. The data are for each pot of two plants. The results of these experiments appear in the table below:

TABLE IV

Grams nitrogen recovered in harvested material per pot of two plants.

Treatment						
No. of Appli-cations	Gms. N per Appln.	Total Gms. N applied	Theoretical recoverable	Total Det'd in dry matter	Difference between theoretical and found	Undetermined for each ½ gram increment
1	.5	.5	.610	$.451 \pm .005$	.159	.159
2	.5	1.0	1.110	$.851 \pm .005$	.259	.100
3	.5	1.5	1.610	$1.275 \pm .006$	.335	.076
1	1.5	1.5	1.576	1.288	.288	....

It will be noted from the above table that while the loss for each increment is greater for the one made earlier, the total quantity unrecoverable at the period of maximum content was nearly the same for both the split and single applications of 1.5 grams of nitrogen.

While the results of these studies have suggested the possibility of loss of nitrogen during the early period of plant growth coincident with absorption, and during the later stages of growth after the concentration of this nutrient has reached a maximum, the real reasons for this phenomenon are still vague and indefinite. Possible explanations which have been suggested are: (1) nitrogen added to the soil may have become immobilized in the organic fraction of the soil as indicated in studies discussed in the first part of this report, and all of the nitrogen thus fixed may or may not become available later upon nitrification; (2) nitrogen may become dissipated to the atmosphere either as gaseous oxides or in the elemental form through bacterial or chemical reactions; and (3) nitrate reduction in plant tissues may set nitrogen free as discussed by Pearsall and Billimoria (27). As suggested by these English investigators, this phase of nitrogen metabolism in plants deserves further consideration.

This apparent deficiency between the amount of nitrogen applied and the amount recovered has practical significance when plant analysis is to be used to determine the needs of a crop. Thus, if upon analysis at maturity, the crop is found to contain a certain quantity of nitrogen, this may or may not represent the amount needed at an earlier period in its growth. Due to the possibility of a loss of nitrogen from

the tissues, the requirement for this nutrient may have been higher than that indicated by analysis at maturity.

Growth of Sugar Cane and Nitrogen Absorption:

The point has often been raised as to whether a continuous absorption of nitrogen is necessary for the best growth of the cane plant or whether large amounts taken up at some one period can carry the crop to maturity or for a sustained period of growth. The solution of this has a bearing on the practical aspects of nitrogen fertilization as it concerns the problem of single or split applications. Many investigators have indicated that plants may be able to store up nutrients above their momentary needs in their tissues and draw upon these stores for growth. The results of this present study have indicated that the cane plant can absorb large quantities of nitrogen at a rapid rate during its early period of growth. This nitrogen content of the plant material as a result of absorption reached a maximum within a period of 90 days. However, growth during this period yielded less than one-half of the total dry weight including roots which was obtained at 210 days. The data of nitrogen absorption and growth, as indicated by yield of dry matter, are presented in Fig. 14. From this graph it will be seen that growth did not parallel absorption, that is, growth did not end with the cessation of absorption. Growth between the eighth and the twenty-third week proceeded at a constant rate of increase, whereas nitrogen absorption had ceased and reached the maximum after the twelfth week.

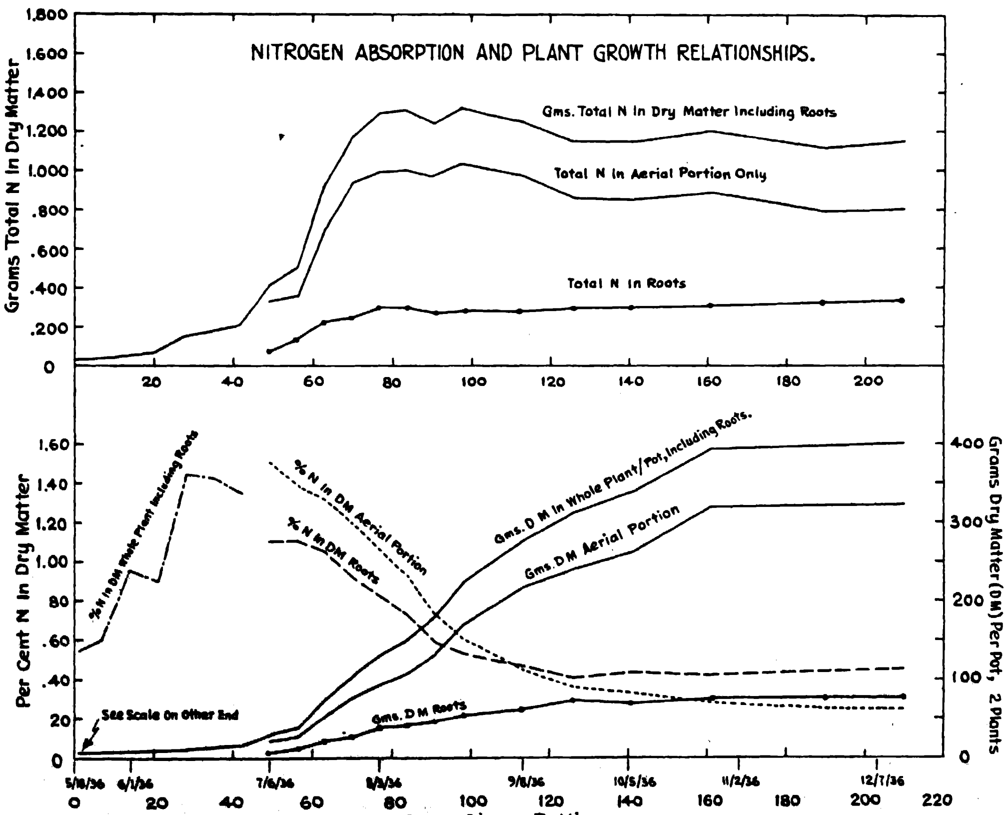

Fig. 14

It may be inferred that if a sufficient amount of nitrogen is supplied, and providing that this element is the limiting factor, the nutrient even if absorbed during the early period when only little growth is taking place, will suffice to carry the crop to maturity.

Importance of an Adequate Supply:

The requirement of an adequate supply is evident from the results obtained in another similar experiment. To one series of pots was added ½ gram of nitrogen, to another 1.0 gram, and to the third series 1.5 grams of nitrogen, all from ammonium nitrate solution. The nitrogen was added in ½-gram increments. The first increment of ½ gram was added to all pots at the same time. Each subsequent increment of nitrogen to make up the required total was added to the pot as a surface application as soon as the soil analysis showed the previous application to have been absorbed by the growing cane. Periodic harvestings were made to determine the growth throughout the period of the experiment. The results presented in Fig. 15 appear to indicate that the ½-gram application was not sufficient to make sustained growth. The cane was able to make additional growth for only 56 days after the ½ gram of nitrogen was absorbed or approximately 104 days after potting. The second and third fertilization making total applications of 1.0 gram and 1.5 grams of nitrogen respectively, extended the growing period to 154 days, as compared with 104 days for the ½-gram treatment. The third increment increased the rate of growth over that shown by the 1.0-gram treatment.

Effect of Single and Split Applications of Nitrogen on the Yield of Sugar Cane:

In field experiments with sugar cane the results showing the relative efficiency of single versus split applications have not been conclusive. This phase will be con-

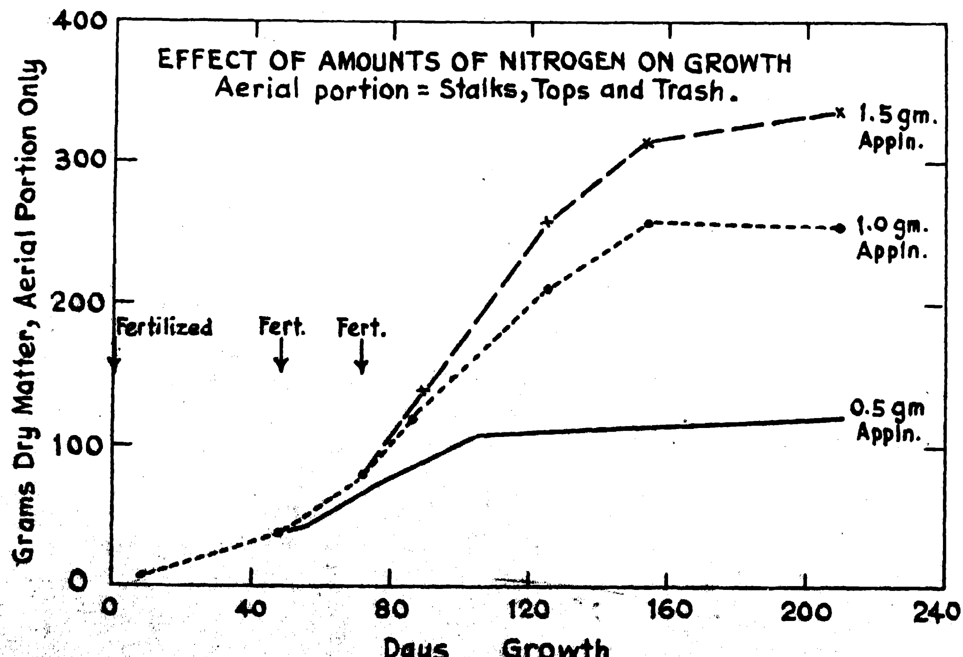

Fig. 15

sidered for cane growing in pots. The rate of absorption of nutrients by sugar cane resulting from single or split applications of 1.5 grams of nitrogen per pot of two shoots have been reported in Figs. 6 and 8. The yields of plant material for these treatments are being presented for examination. It will be recalled that the split applications were divided into three series: Series 1, nitrogen applied whenever soil analysis showed the previous application to have been removed; Series 2, nitrogen applied one week after the previous application had been removed; and Series 3, nitrogen applied only when the plants showed definite symptoms of deficiency as evidenced by the uniform yellowing of foliage. The yields of dry matter of different parts of the cane plant for the single application and for the three series are presented in Table V. The data shown in the table represent averages of five pots for each treatment:

TABLE V

Yield of dry matter as a result of single and split applications of 1.5 grams of N per pot of two H 109 cane shoots. Four and one-half kilograms of soil amply fertilized with phosphate and potash.

	Grams Dry Matter Harvested			
Treatment	Roots	Trash	Green Tops	Millable Stalks
Single application	69.7	126.3	49.6	134.2±2.6
Series 1	88.7	149.7	44.3	143.0±4.2
Series 2	78.7	143.9	50.4	132.4±4.4
Series 3	74.4	130.0	54.2	117.0±3.1

It will be seen from the above table that a significantly greater production of millable stalks is possible if the application is split and applied continuously without delay (Series 1) than if the nitrogen is split and applied only when the plants show deficiency symptoms (Series 3). A single application versus Series 1 and 2 did not show a significant difference.

A similar trend showing lowered production resulting from too long a delay in fertilization may be found from the results of the experiment concerned with the time of application with respect to age, in which the rate of nitrogen removal is shown in Fig. 10. The yield data for this experiment follow:

TABLE VI

Yield of dry matter resulting from a time-of-nitrogen-application test of H 109 cane in pots. Total growth, 94 days after potting. PK added at start, N at variable intervals.

	Grams Dry Matter Harvested				
Treatment	Stalks + tops	Trash	Roots	Aerial portion of plant	Total, incl. roots
N at start..........	156	75	59	231	290
N at 21 days.......	173	80	62	253	315
N at 42 days.......	182	75	42	257	299
N at 56 days.......	157	68	53	225	278
N at 84 days.......	159	43	44	202	246

The results of the test appear to indicate that when nitrogen was applied in the twelfth week after transplanting, the yield of dry matter was not as favorable as for the earlier applications. Fertilization at 3 to 6 weeks after the transplanting of the month-old shoots appears to be the optimum for growth. The soil in these pots was low in available nitrogen at the beginning of the crop.

General Discussion of Results With Respect to Field Problems

It is apparent that nitrogen analyses by rapid chemical methods may be used as an aid to intelligent nitrogen fertilization. Although some wide fluctuations are likely to occur in analyses of individual soil samples from the same area, such variations need not be considered too great to afford a fairly reliable interpretation, when the limitations of the analysis are fully recognized. Hence it is believed that when a "high" level of available nitrogen is found, one may conservatively figure on at least 50 per cent of the indicated amount as being immediately available for crop growth, and that an allowance may be made for this in the subsequent nitrogen fertilizer application.

An interpretation of a "low" level of available nitrogen in the soil sample in relation to growth during a long period of time is somewhat difficult. Until more evidence is available, one must be cautious in an interpretation. Cropped soils usually show this "low" level, although the crop growing on such soils may have taken up a very large supply which it apparently can store up and continue to use. Data from these studies indicate that growth continues long after nitrogen absorption ceases (when due to the depletion of the available supply in the soil) and that such growth is apparently regulated by the amount of nitrogen which was absorbed before this point was reached.

It is quite apparent that where a real nitrogen deficiency exists at the start of a crop, as indicated when the R.C.M. nitrogen analyses at this time show less than 40 or 50 pounds per acre-foot, a delay in the application of nitrogen fertilizer will result in retarded growth which will be quite evident when the delay extends for a period of more than 5 or 6 weeks. On the other hand, if a readily soluble nitrogen fertilizer is supplied too early, i.e., before the root system is well started, the rate of absorption is only about half as fast as it is when the root mass has more fully developed. Hence, under field conditions where loss of nitrogen by leaching can be expected, or where the biological activities of soil organisms are taking up their quota from this available nitrogen, one can expect that the quantity of this nutrient which is obtained by the immediate cane crop from an early application will be somewhat less than that from a late fertilization when the plants are able to absorb this nutrient more rapidly.

Both the time of applying the nitrogen (with respect to an adequate development of the root system) and the amount of nitrogen supplied have been shown to affect its rate of absorption. Similarly the time of applying both phosphate and potash shows its influence on the uptake of nitrogen, for when P_2O_5 or K_2O, singly or combined, were supplied three weeks after the nitrogen application had been made, the nitrogen uptake was considerably delayed; this was especially true when the phosphate application was late.

The fact that only a negligible amount of the applied nitrogen was found in the soil three months after an application had been made to one-month-old cane growing in pots, and also that the complete uptake of nitrogen by the cane from an application which was made when the crop was four months old was accomplished in less than 30 days, leads one to feel that even under field conditions, if the nitrogen fertilizer is applied in an active root-feeding zone, its rate of absorption therefrom will be quite rapid.

Summary

Soil and plant nitrogen studies have been conducted to obtain information pertinent to the application to field problems of the data determined by rapid chemical analyses. This report includes many of the results obtained in these studies. Tests on uncropped soils were undertaken to trace the variations of the available nitrogen supply in original air-dry soils and in soils which had received this nutrient as a fertilizer. Experiments were made to determine the rate of nitrification of ammoniacal nitrogen added to certain acid soils and also the extent of seasonal influences upon nitrogen availability.

The studies of uncropped soils have indicated that the nitrification of added ammoniacal nitrogen proceeds as a normal occurrence in the acid soils examined. The rate of nitrification is variable, and the process does not necessarily occur as a quantitative reaction.

Wide fluctuations have been noted in the analysis of uncropped soils sampled between short and long intervals of time. The long-range fluctuations may indicate the influence of seasonal differences. In general it was found that available nitrogen increases in the fall and winter, declines in late spring and continues through the summer.

Measurement of the availability of nitrogen by R.C.M. does not give the amount which may be available through a long period of time but merely gives the amount which is present at the moment. Levels of fertility have been suggested for this nutrient as determined by the chemical analysis.

In addition to the studies on uncropped soils, the fate of added nitrogen and the level of this nutrient in soils supporting plant growth were investigated. By growing sugar cane (H 109) in a series of Mitscherlich pots to which nitrogen was added, and by obtaining periodic samplings of soils and plant materials for nitrogen determinations, the rate of absorption and recovery of this nutrient were studied during the growth of a crop. Other studies included the relationship of fertilization to yield and composition of H 109 cane in pot growth, and the effect of single and split applications of nitrogen on the yield of this sugar cane.

These soil and plant nitrogen studies have indicated that when plants are growing in a soil, the available nitrogen level for that soil is usually low.

The cane plant can rapidly remove from the soil the available nitrogen which was either originally present or is later applied. The rate of absorption appears to depend upon the time of application with respect to the age of the plant or probably with the development of its root system, and is apparently independent of the needs of the plant.

Nitrogen absorbed beyond the requirements of the moment may be stored up and used for later growth. Thus it is possible for the cane plant to absorb nitrogen from one application at an early stage of its life and without further uptake continue to grow for a period which is probably dependent upon the quantity which had been absorbed.

The timing of the nitrogen application may be an important factor in the growth of cane; the efficiency of split versus single applications is in a measure dependent upon the time of application of the successive split portions.

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Trends in Irrigation Practice

By H. A. Wadsworth

Papers dealing with current irrigation practices with sugar cane in Hawaii were presented at the Annual Meetings of the Hawaiian Sugar Planters' Association in 1931 and 1932.* In addition to descriptions of irrigation practices then gaining favor with the industry, each report included a statistical summary of the areas served by each of the methods then in common use.

The purpose of the present paper is to review the same material after a lapse of five years, to report modifications in the trends suggested by the two reports which have been mentioned, and to note the effects of the changing emphasis of economic conditions and labor relationships upon the actual handling of water in the field.

Although it is probable that improvements in practice are too slow to justify such summaries every year, it is evident that considerable historic detail has been lost in the period since 1932. For example, the Koloa method, first developed in 1927, was used on about 20 per cent of the total irrigated area by 1931. By 1932 the area had increased to 25 per cent of the total. Less than one per cent of the total irrigated area was supplied by the Koloa method in 1937. A similar history of rapid expansion and equally rapid decline may be noted in the history of the Wailuku huli-huli method.

In retrospect it is not surprising that such rapid changes should have occurred. Increasing costs of water emphasize the necessity of careful use. Low sugar prices necessitate the reduction of costs of production. Whenever such prices prevail every effort is directed toward the end of cheap land preparation and the speeding up of the actual application of water. Labor shortages, present and imminent, demand the development of irrigation practices which may not only require a minimum of labor in irrigating but which may leave the fields as open as possible for the use of cultivating and harvesting equipment. The point of emphasis has changed frequently since about 1928. The industry is now faced with a situation necessitating the production of low-cost sugar with a minimum of labor. Irrigation practices are available if this is the only end desired, but other desirable characteristics, such as low cost of land preparation and extreme flexibility may, of necessity, be sacrificed toward that end.

Extension of Long-Line Practices:

Outstanding in almost universal acceptance by plantations during the past six years has been some form of the long-line method of irrigating. Although a standard practice with row crops in most irrigated areas the scheme of allowing water to seep into a soil only while water is flowing over it was not introduced into Hawaii

* Developments in Irrigation Practice (1931) H. A. Wadsworth and H. R. Shaw. Proceedings, Fifty-first Annual Meeting, Hawaiian Sugar Planters' Association; and a Report upon Progress and Performance of the Newer Methods of Irrigation (1932) H. R. Shaw. Proceedings, Fifty-second Annual Meeting, Hawaiian Sugar Planters' Association.

until about 1922 when the method was tried experimentally at Kilauea Sugar Plantation Company, Ewa Plantation Company, and Maui Agricultural Company. Since that time the expansion of the long-line method of irrigation has been phenomenal because it permitted marked reduction in irrigation costs during the period of low sugar prices. Since fields prepared for long-line irrigation not only require fewer man-days per crop in the actual application of water but also leave the field in fair shape for mechanical harvesting devices, the general scheme seems to be entering a new field of usefulness. From a small beginning in 1922, fields irrigated by the long-line method covered 5 per cent of the total irrigated cane area in 1931 and about 8 per cent a year later. The present summary indicates that almost 50 per cent of the irrigated cane land in Hawaii is irrigated by this method.

Such comparisons are difficult and not particularly reliable because of the terminology used in early reports. "No watercourse system," "automatic irrigation" and the "Baldwin flume system" were undoubtedly early efforts toward long-line distribution. Later terms such as "long contour" and "modified orchard" were attempts to distinguish between different general classes of long-line installations.

Valuable as these terminologies may have been during the formative stages of the practice they seem to have fulfilled their usefulness. In the present summary, long-line installations are divided into two classes: first, those in which the irrigation lines are supplied from a service ditch which is on the contour or nearly so; and second, those in which the irrigation lines are supplied from a service ditch which runs directly down the slope, the cane lines themselves leaving the service ditch at right angles or obliquely depending upon the topography and the desired slope in the lines. Ordinarily such an arrangement is called the "Herringbone layout."

Such a classification seems rational not because of any differences in the manner in which water is applied to the roots of the plant, but because of the different problems which are presented.

In the first case we have a supply ditch carrying water under a low velocity. No protection from erosion is necessary. The only problem, aside from those involved in establishing the proper slopes for the lines themselves, is to provide a sure and positive device for getting water through the ditch bank or over it in variable amounts, when delivery is desired. Ditch siphons, concrete or galvanized iron pipes fitted with gates of some sort or wooden boxes extending through the ditch banks are examples of these devices.

Long-Line Irrigations from Service Ditches on the Contour:

Two outstanding trends are to be noted in the handling of long-line irrigation. The first of these is the growing appreciation that the irrigator must have considerable leeway in the regulation of water admitted into each line. It is evident that on a given slope a smaller head of water must be used in a newly planted field because of danger of wash. And it is equally evident that a very large head is required when cane is heavy and recumbent. The amount that can be satisfactorily used increases with each irrigation.

As has been indicated the use of simple pipes through the ditch bank, which were either entirely open or completely closed has been almost completely abandoned in favor of pipes fitted with adjustable shutters of one sort or another. Moreover the

effective diameters of such pipes have been constantly increasing as experience is gained. Modern pipes are so large that concrete is the favored material.

In the Hamakuapoko section of Maui Agricultural Company the inlet pipes are complex in an effort to provide for the increasing head of water which may be used, and still permit rapid and accurate manipulation at the time of irrigating. In order to accomplish this end, the gate fitting consists of two parts. One of these is a shutter covering part of the pipe and held in place by a wing nut. The other is the conventional gate which is either entirely open or completely closed. In operation the irrigator opens the gates into as many lines as the water supply permits, and relies upon the inner shutter to regulate the flow in accordance with the particular demands of the line. Adjustments of the inner shutters are made as the crop demands. This type of ditch pipe is shown in Fig. 1.

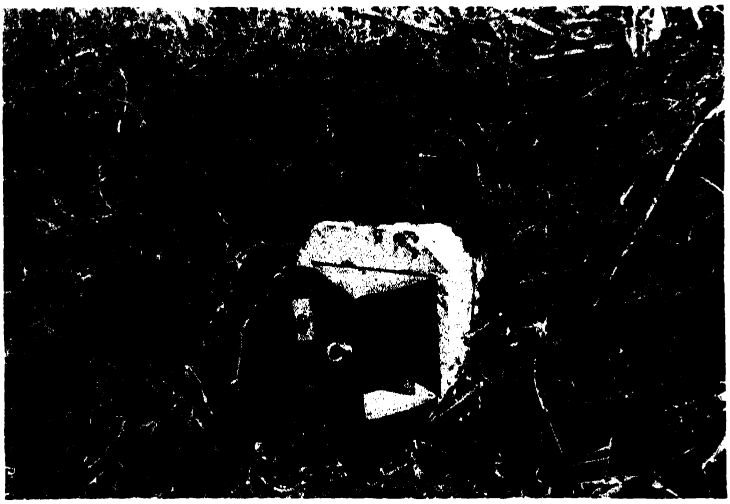

Fig. 1. A long-line service ditch fitting—Maui Agricultural Company. This fitting for a service ditch on the contour is featured by dual control. The inner gate, adjusted by the wing nut, is set to admit the proper amount of water to the line when the outer gate is open. The large concrete box shows the influence of increasing sizes in these fittings.

The other marked trend in long-line manipulation is a growing appreciation that speed in filling a long line on a slope is not the only desideratum. Since water can seep into the soil only during the time that water is flowing in the line, it is evident that this time must be long enough to provide adequate penetration. The evident procedure, if acceptable performance per man-day is to be secured, is to irrigate more lines at a time with a smaller flow in each. It is only in this way that increased acreage per man-day and adequate irrigation can be secured.

Simple as this conception may be it is difficult to modify the line-by-line concept of the irrigators themselves. Here, it would appear, is a fertile field for adult education.

An interesting development in the operation of long-line irrigation layouts is to be noted on plantations on the windward sides of Oahu and Kauai. In these areas

irrigation lines are at times drawn between adjacent cane rows in place of directly over the plants in deep and carefully maintained lines.

It is to be noted that a tough and relatively impervious subsoil, probably resulting from the intense rainfall, is to be found in the regions noted. Such a subsoil apparently modifies the seepage pattern resulting from long-line application and gives much greater lateral spread than would be expected with a deeper and more uniform soil. Good use is made of this unusual character at Kilauea Sugar Plantation Company. Here the plant crop is grown in lines similar to those used elsewhere but somewhat more shallow. During ratooning operations the line is filled and subsequent irrigations, during the life of the planting, are in temporary, shallow but broad lines drawn between the rows. Such a practice readily lends itself to mechanical cultivation.

Efforts to use this practice on the drier plantations have not been successful. In such cases the lateral seepage, even from wide shallow furrows seems insufficient to carry adequate moisture into the root masses directly under the plants. However, it is recognized that continued mechanical cultivation of old ratoons tends to result in flat culture of this sort.

Long-Line Irrigation from Service Ditches on the Slope:

In the second case, that is the case in which the service ditch runs directly down the slope, the problems are quite different and hydraulically much more difficult. Here the velocities are no longer negligible but may be very great. In one ditch at Wailuku Sugar Company, a velocity of more than 20 feet per second was noted. Not even the soils of Hawaii can withstand the erosive action of water under such velocities. Some sort of ditch lining is required in most cases although it is dispensed with in some. Great ingenuity has been shown in providing such lining. In the earlier installations this reinforcement was provided by wooden flumes framed in the shop and joined in the field on the selected location. Other more recent attempts have used concrete, sometimes cast into triangular flume sections and sometimes in trapezoidal form. In still other installations pipe either of concrete or steel is used. But in all cases the ends in view are to protect the ditch location from erosion and to increase the carrying capacity of a small ditch section to such an extent that ever-increasing areas can be served in a given time. One of the trends of the times is the growing appreciation that increased areas per man-day can only be secured if the man is supplied with a correspondingly increased quantity of water.

Providing facilities for removing water from the flume or pipe has given greater difficulty than providing the ditch reinforcement. When wooden flume is used, galvanized iron shutters which fold tightly against the side of the flume when the opening is to be closed and which divert any given amount into the lines adjacent as the shutters are swung out into the section, may be used. The work of H. W. Baldwin, of Maui Agricultural Company, with devices of this sort has been largely responsible for the success of this type of long-line irrigation.

The use of other materials than wood for flumes has necessitated the development of other devices for delivering water to the lines. At Waialua Agricultural Company, precast concrete sections of flume are cemented together in the field on the line of the service ditch. At five-foot intervals a section carrying an integrally

Fig. 2. Precast concrete flume—Waialua Agricultural Company. Here the water in the flume enters the box below and subjects the galvanized iron gates to some pressure. Discharge is controlled by manipulation of the gates. Such gates tend to leak, particularly after some use.

Fig. 3. Service flume with side ports—Waialua Agricultural Company. The tight-fitting slides prohibit leaks from the flume; the rolled top permits the use of an even, small flow in the flume.

cast cross box is installed. Being open to the flume by a port in the bottom, the cross box is under pressure when water is in the flume (Fig. 2). Delivery to the lines is made through galvanized iron gates which are installed at the ends of the box.

More recent practice at Waialua Agricultural Company involves the use of an almost rectangular, precast flume section provided with outlet ports on either side at five-foot intervals. Narrow slots cast in the outlet ports permit the insertion of plane iron shutters which regulate the flow with negligible leak under maximum

Fig. 4. Galvanized iron surface pipe—Honolulu Plantation Company. Here galvanized iron pipes, fitted at necessary intervals with tight slide gates, extend down the slope carrying water under considerable pressure. Note that the line is not completely buried.

Fig. 5. Discharge from surface pipe used as a service ditch—Honolulu Plantation Company. Here the velocity might result in considerable damage to the line, if it were not controlled as shown in Fig. 6.

pressure. Such a flume in use is shown in Fig. 3. The rolled top on the gate is used to deflect water toward the outlet port when great discharge is required or when the flume is practically empty.

In another ingenious device on the same plantation, the velocity of the water in the ditch is used to force a portion of the stream over the sides of the flume and into the cane rows. In order to accomplish this a T-shaped member of large-diameter galvanized iron pipe is so placed that the long arm extends up the ditch while the short arms span it and extend for some distance on either side. The velocity head

Fig. 6. Erosion control—Honolulu Plantation Company. Here the fast-moving jet from the partially opened port is introduced into a burlap sleeve and then delivered to the line.

Fig. 7. Opening a port in the surface pipe—Honolulu Plantation Company. Gates fit tightly to prevent leaks; a special tool is provided to adjust them.

of the water entering the submerged pipe is converted into pressure causing water to rise in the pipe to the elevation of the junction with the crossarm through which it flows over the sides of the flume and into the lines. It is evident that this scheme is suitable only for use with flumes carrying significant velocities.

When such flumes extend down slopes of varying gradient it is evident that the maximum capacity of the flume will be governed by the capacity of the section on the flattest slope. In some installations this difficulty is corrected by using flume sections of greater cross-sectional area on the flatter slopes, although this in extreme cases may be so costly as to be impractical. Another alternative lies in the use of pipe in place of flume. When pipes are used the capacity of the pipe is governed

Fig. 8. Pressure pipe delivery to long lines—Pioneer Mill Company. Water is delivered to long lines on either side of the pipe by manipulation of the metal gate sliding in a block cast to the pipe sections. Since the pipe is under pressure large heads of water can be handled and delivered to a number of lines at once.

mainly by its diameter and the total difference in elevation between the ends, and only slightly by differences in slope along the line.

Three notable examples of the use of pipe as a service ditch justify particular mention. Two of these, one at Honolulu Plantation Company and one at Pioneer Mill Company, differ only in the material used. At Honolulu Plantation Company heavily galvanized iron pipe of six-inch diameter is used. Twenty-foot lengths of this material can be easily carried and quickly assembled into a continuous leak-proof line by the use of cone and spigot couplings. Ports in either side, covered with shutters sliding in tight fittings (Figs. 4-7) permit the withdrawal of water for the lines which are conventionally located. At Honolulu Plantation Company the galvanized iron pipe is buried only when it crosses the ridge between adjacent lines. It is evident that water released through the ports will assume considerable velocity (Fig. 5) particularly along the lower ends of the pipe where the pressure is great. Erosion from this source is eliminated by the use of sleeves of burlap, as shown in Fig. 6, which are hung on the pipe and cushion the point of impact.

At Pioneer Mill Company concrete pipe is used in place of galvanized iron, as shown in Fig. 8. This pipe, cast on the plantation, is made in such lengths that a section, carrying side outlets covered with iron shutters, can be set at five-foot intervals. In operation the system is similar to that wherein galvanized iron pipe is used. When water is introduced at the upper end, the pipe is subjected to a pressure which, of course, varies with the vertical distance separating the surface of the water at the intake and the point in question. The varying discharge which would result if uniformly sized discharged ports were ~~used-can~~ be corrected by adjustment of the galvanized iron slides which cover them.

Mention has been made of the pressure developed within lines laid in this manner. Although no local installations as yet demand great care in design to keep the

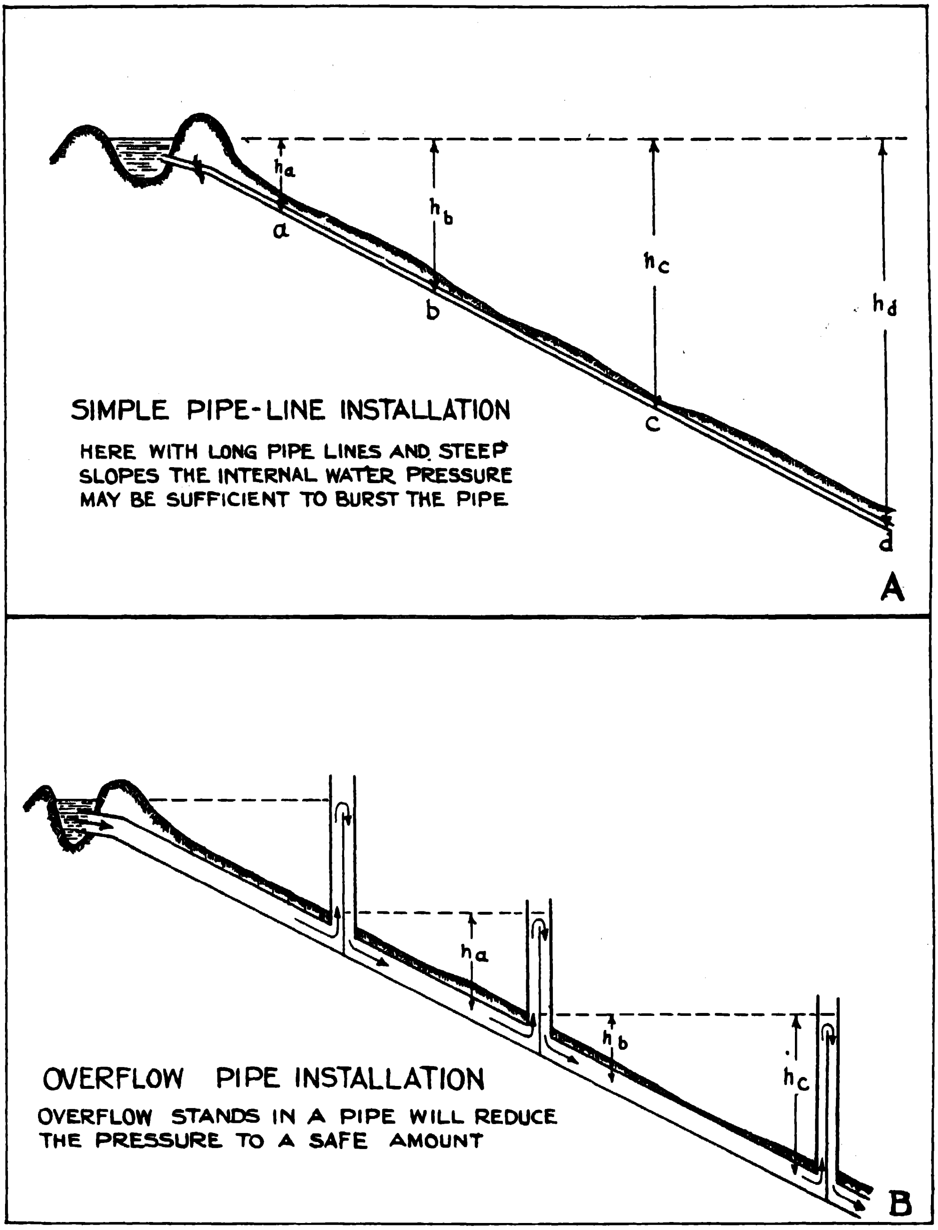

Fig. 9. Typical concrete pipe installations—diagrammatic representation of pressure relations in concrete pipe. Excessive pressure as in "A" can be avoided by use of overflow stands as suggested in "B."

pressure within the limit tolerated by the material in question, it is evident that extension of the practice may provide difficulties. Such a pipe is shown diagrammatically in Fig. 9. Here, in "A," a pipe line of indefinite length runs down a slope from a supply ditch, its end being "hd" feet vertically below the free-water surface. If all ports are closed at the time water is admitted, a condition which must be allowed for, the pressure, in feet of water, at any point is equal to the vertical distance separating that point from the free-water level. At the lower end the pressure is, of course, "hd" feet and intermediate pressures are as shown.

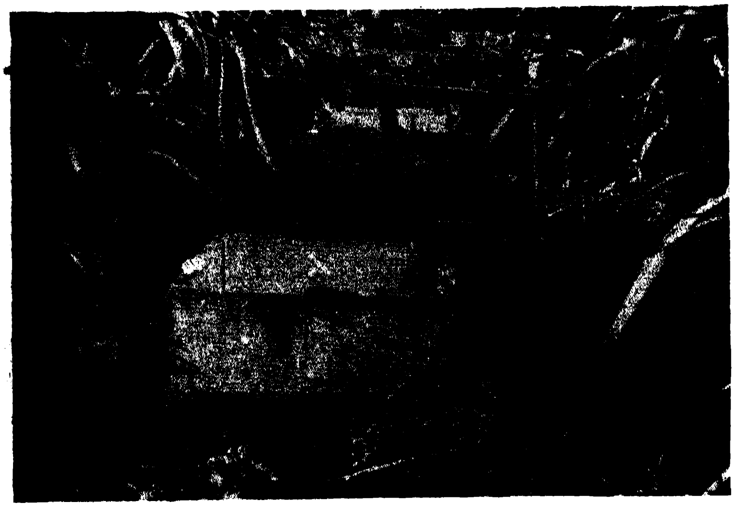

Fig. 10. An overflow stand—Pioneer Mill Company. When the wooden gate is lowered into the box, water rises above it, and submerges the large pipes leading to two-line borders on either side. This method, although costly, is highly effective in handling freshet flows.

Fig. 11. Concrete pipe in operation—Maui Agricultural Company. Manipulation of the gates in the bottom of the pipe permits delivery to either or both sides of the line. The handhole in the top allows for the removal of trash and for the adjustment of the gates. The plug at the left eliminates splash when the pipe is full.

Unreinforced concrete pipe, particularly if dry-mixed and hand-tamped, is not outstandingly high in tensile strength, nor are successive castings markedly uniform. Any section placed by chance in a location demanding a resistance to pressure greater than that built into the section must fail with concomitant cost and delay. It is doubtful if much of the plantation-made concrete pipe now in use has a tensile strength in excess of 35 pounds per square inch. If this be true it is evident that no single line should be long enough to create a difference in pressure of more than 80

feet at the head of the line. One should be quick to say that this figure of 35 pounds per square inch applies only to common pipe. By the use of a wet mix, machine tamping or internal reinforcing this figure can be greatly increased.

Methods of relieving this pressure are available. One common method is already in use at Pioneer Mill Company. Here the water is introduced into the line as usual but in place of being sealed throughout its length, the line is broken at frequent intervals by overflow stands. The pressure on any section may be reduced to any specified maximum by increasing the number of such stands. The simple hydraulics of the system is shown in Fig. 9-B.

Although this installation at Pioneer Mill Company illustrates the principle of overflow stands as a means for relieving pressure, it was not built for that purpose. A series of two-line borders were to be supplied with water from a ditch which might carry freshet water requiring expeditious handling. The pipe installed was of large diameter and so buried that when usable heads were used no discharge at the surface was possible in view of free discharge below. Overflow stands were so installed (Fig. 10) that when crude wooden gates were set in them the water rose in the upstream sides of the boxes and flowed over the gates into the pipe line below. When this was done concrete pipes leading from the overflow stand were submerged and delivery into the adjacent borders effected. Phenomenal increases in the area irrigated per man-day are reported for this practice. It is evident that the installation is costly in terms of dollars per acre.

Plantation-made concrete pipe, used as flume in the Hamakuapoko section of the Maui Agricultural Company, provides the third example of the use of such material as a service ditch on a significant slope. Here the pipe is not expected to operate under any great pressure head; in fact handholes in the top of the pipe as shown in Fig. 11 prevent the development of pressure. When cast in the yard (Fig. 12) each section is provided with two square holes in the bottom as well as the larger one in the top which has been mentioned. When installed the two bottom holes discharge water into a partitioned concrete saddle which delivers it to the lines on either side. Adjustment of water to the lines is effected by means of iron shutters which fit over the bottom openings in the pipe. The shutters can be operated by a heavy wire handle which extends beyond the pipe and which is shown in Fig. 13.

Irrigation by the Border Method:

An indicated in Table I, the area irrigated by the border method has increased markedly since 1932. From an area equal to 4.1 per cent of the total in 1932, the area irrigated by the border method in all its forms had increased to 9.3 per cent of the total in 1937.

It should be noted, however, that most of this increase is to be found in the use of two-line borders. In only one plantation has there been an increase in the area irrigated by four-line borders, between the dates of the two surveys.

There seems to be no consensus of opinion as to the apparent failure of the four-line borders to live up to their early promise. In many cases reported, particularly at Pioneer Mill Company and Lihue Plantation Company, the two inside lines, in a four-line border, have been definitely inferior. But whether this is due to the stimulation of the outside rows by the abundance of surface soil heaped up in the near-by

Fig. 12. Concrete pipe yard—Maui Agricultural Company. The pipe sections are cast with two square openings in the bottom and one in the top. (See Figs. 11 and 13.) Note the concrete box saddle in which the pipe rests and the unique serrated tops of the pipes.

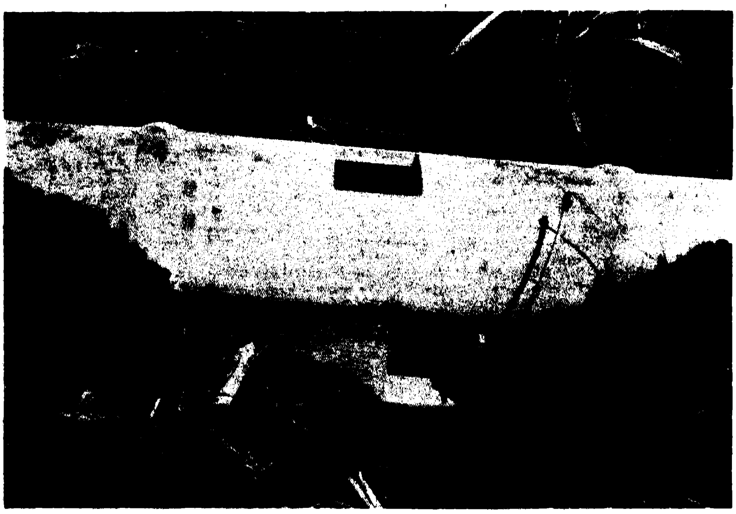

Fig. 13. Concrete pipe for Herringbone layout—Maui Agricultural Company. Water in the pipe is delivered to the lines through the square saddle on which the pipe rests. Galvanized iron gates inside the pipe control the flow. They are operated from the outside by means of the heavy wire handle.

ridge, or to the loss of surface soil in the center of the border, or to unsatisfactory distribution of water is not clear. Moreover some plantations, particularly Hawaiian Commercial and Sugar Company have experienced great difficulty with erosion within the borders. Here care and money were freely spent in the building of cross dams and barriers of trash and lumber to reduce erosion to a tolerable degree.

Two-line borders are of increasing popularity. At Pioneer Mill Company and Ewa Plantation Company this method of irrigation is being used not only on slopes

too steep for the four-line borders but also in topography which seems well adapted to the wider border. It is evident that the difficulty of having the two interior lines inferior disappears when the narrower border is used.

It is also evident from a scrutiny of the local history of the method, that borders were often established on slopes that were too steep for the securing of adequate penetration. The apparent correction of irrigating many borders simultaneously, toward the ends of increased penetration and elimination of erosion, is being practiced at Ewa Plantation Company.

However, the fact remains that borders lend themselves to mechanical cultivation. A spinner similar to those used on many plantations is shown in operation in Fig. 14.

Fig. 14. Weed eradication in young ratoons in borders—Ewa Plantation Company. Spinners and other mechanical cultivators find great use in fields laid out for irrigation by the border method.

Two-line borders, served from the concrete, overflow pipe line which has been mentioned, have been satisfactory at Pioneer Mill Company. Ditch water available for this area is subject to great variations in flow. Freshets of a few hours' duration are not uncommon; a means for distributing this water quickly must be provided. With the two-line contour borders on such flat slopes that erosion is minimized, it is evident that a large stream of water can be handled by one man when the overflow gates are properly manipulated. It is said that some fields at Pioneer Mill Company provided with irrigation by this means have been brought to maturity with but three man-days of irrigation labor per acre during the life of the crop.

Overhead Sprinkling:

Recent developments in overhead sprinkling equipment on the mainland, and the local incentive to perfect a method of irrigation which will not only require a minimum of labor in irrigating but will also leave the field clear of internal structures, again draws attention to the possibilities of this long-debated method. The use of

this method of irrigating has increased markedly in recent years on the mainland because of improved equipment. Such equipment, which has led to the use of portable sprinklers, with great reduction in first cost, has extended the possibilities of overhead sprinkling into such low-value crops as alfalfa, beans, and sugar beets.

Two developments have made this possible. The first of these is the perfection of a light, thin-wall, large-diameter pipe which can be used in temporary field lines and which because of its large diameter may serve many modern sprinklers simultaneously. The ends are reinforced with special fittings which permit the rapid assembly of a leak-free line.

The other important development lies in the improvements in the heads themselves. Modern heads are large, heavy and relatively costly. Some of them deliver as much as 50 gallons per minute under a pressure of about 50 pounds per square inch. With such heads it is possible to get acceptably uniform coverage over an area 150 feet in diameter.

A field equipped for modern overhead sprinkling is provided with a single pressure line along the upper edge of the field, fitted with capped outlets at intervals of about 125 feet. Lines of portable pipe which at times are 1000 feet long, if pressure permits, are connected to each of these in turn. These portable lines are provided with fittings into which vertical pipes, carrying the sprinkler, may be screwed. Under the conditions noted, such pipes, or risers, would be about 125 feet apart. Ordinarily two lengths of portable pipe are provided, one being placed while the other is in use.

It is clear that such a practice differs widely from the overhead installations formerly used with sugar cane in Hawaii. Emphasis has previously been laid upon the design and use of inexpensive heads with small diameters of coverage. The lack of uniform coverage secured from them and the complexity of the pipe system required to serve them contributed largely to the disappointment resulting from their use. As has been indicated, modern heads sacrifice low first cost to wide coverage and uniformity of distribution. Since a permanent installation of pipe for heads of such heavy discharge is economically impractical, a portable system is indicated. The development of the light pipe, with the quickly operated couplings which have been mentioned, make such portable lines possible.

Certain values may be anticipated from the use of modern overhead sprinkling methods with sugar cane. Although no figures are available for the labor requirements with this method in sugar cane, it seems probable that they will not exceed those of the better long-line installations. Moreover the area must lend itself to economical animal and machine cultivation because of the complete absence of permanent structures inside the field. For the same reason mechanical harvesting may be more expeditious.

High in the list of possible disadvantages is first cost which may range from $60 to $100 an acre, according to the inadequate figures available. Since each area is a special problem requiring its own design, uniform first costs are improbable. In fortunate cases in which gravity pressure is available the first cost may be considerably less than that given.

A small area of about four acres is now under modern overhead irrigation at Waialua Agricultural Company. The extension of this area to a size suitable for

detailed cost studies is proposed. The adoption of this method on other areas of similar size at Kekaha Sugar Company and at Grove Farm Company is under consideration.

Small as the area at Waialua Agricultural Company is, it may well be that the four acres reported for modern overhead sprinkling, marks the beginning of an important trend in Hawaii.

Table I gives the area of land in sugar cane in Hawaii irrigated by the several methods. Here the areas are distributed by islands. In Appendix A the island totals are distributed among the plantations.

Trends in Ditch Lining:

Increased appreciation of the value of water at critical periods and the advent of better sugar prices have stimulated ditch-lining programs which were reported as being held in abeyance in the 1932 report. During the five-year period ending in 1937, seepage protection was provided for almost one million lineal feet of Hawaiian plantation ditch. This is an increase of 38 per cent over the figure given for 1932.

In accordance with the scheme used in 1932 an attempt has been made to separate the ditches into "Main Canals" and "Field Ditches," although this has not always been possible. The results of the present census of ditch lining in Hawaii are given in Table II. Figures contributing to the totals given in Table II are given in Appendix B.

Although the totals for linings of the several sorts, given in Table II, are reported to the nearest foot, no such precision should be read into them. In some cases precise figures were available; in others approximations only were possible. The totals given in Table II are simple summations of the detailed figures reported and may not be reliable beyond the first two figures given.

TABLE I

Acreage of Sugar Cane Irrigated on Hawaiian Plantations by Various Methods, by Islands

Method Used	Hawaii	Kauai	Maui	Oahu	Total 1937	Total 1932	Per cent change based on 1932 return: Increase	Per cent change based on 1932 return: Decrease
Single-line Contour:	1,069	6,201	9,794	5,698	22,762	33,652	..	32
Cut Lines:								
2 lines cut	....	5,272	6,772	805	12,849	31,191	..	59
4 lines cut	....	4,049	....	6,509	10,558	....	..	..
8 lines cut	....	....	....	....	....	8,326	..	..
More than 8 lines cut*	968	223	732	1,748	3,671	17,317	..	79
Long Lines:								
Service ditch on contour	4,911	20,081	14,324	17,348	56,664	10,030	465	..
Service ditch on slope (Herringbone):								
Service Flume:								
Wood	....	10	160	16	186	....	..	..
Concrete	....	305	168	2,478	2,951	....	..	..
Other Material	....	526	25	76	627	....	..	..
Service Pipe:								
Concrete	....	....	897	....	897	....	..	..
Iron	....	....	....	752	752	....	..	..
Koloa:	....	1,244	....	....	1,244	32,969	..	96
Border:								
Service Ditch on Contour:								
4-line borders	....	144	218	6,432	6,764	4,873	39	..
2-line borders	....	46	3,607	826	4,479	495	8C5	..
Service Ditch on Slope (2-line borders):								
Wooden Flume	....	....	58	....	58	57	2	..
Concrete Pipe	....	....	336	....	336	....	..	..
Overhead Sprinkling	198	....	....	4	202	445	..	55
Total	7,146	38,071	37,091	42,692	125,000	129,355		3.3

* Including that previously listed as Wailuku huli-huli.

TABLE II

Ditch Linings on Hawaiian Sugar Plantations, by Islands

Type of Lining	Ditch Lining Complete in Lineal Feet: Hawaii	Kauai	Maui	Oahu	Total 1937	Total 1932	Per cent change based on 1932 return: Increase	Decrease
Main Canals:								
Concrete Cast in Place	17,803	125,598	471,294	103,549	718,244	601,486	19	..
Precast Slabs	4,450	....	29,615	11,880	45,945	57,278	..	20
Cut Stone*	31,106	18,600	19,289	269,011	338,006	261,793	29	..
Cement Plaster	185,063	800	123,180	128,881	437,924	507,800	..	14
Concrete Pipe	....	....	5,327	39,270	44,597	....	..	..
Other Material	27,929	7,750	27,955	154,168	217,802	115,686	88	..
Total for Main Canals	266,351	152,748	676,660	706,759	1,802,518	1,544,043	17	..
Field Ditches:								
Concrete Cast in Place	....	2,500	92,120	6,876	101,496	12,935	680	..
Cut Stone	....	31,000	9,322	92,078	132,400	8,600	1,440	.
Cement Plaster	....	....	324,106	3,160	327,266	69,942	368	..
Wood	....	....	130,028	34,891	164,919	152,777	8	..
Concrete Pipe	....	....	118,869	28,613	147,482	....	..	..
Total for Field Ditches	....	33,500	674,445	165,618	873,563	244,254	258	..
Pipe Lines:								
Pump Lines	18,765	35,542	136,678	203,640	394,625	334,716	18	..
Field Lines, including Siphons	....	53,510	16,456	96,182	166,148	144,607	15	..
Total for Pipe Lines	18,765	89,052	153,134	299,822	560,773	479,323	17	..
Grand Total	285,116	275,300	1,504,239	1,072,199	3,236,854	2,267,620	43	..

* Including field rock.

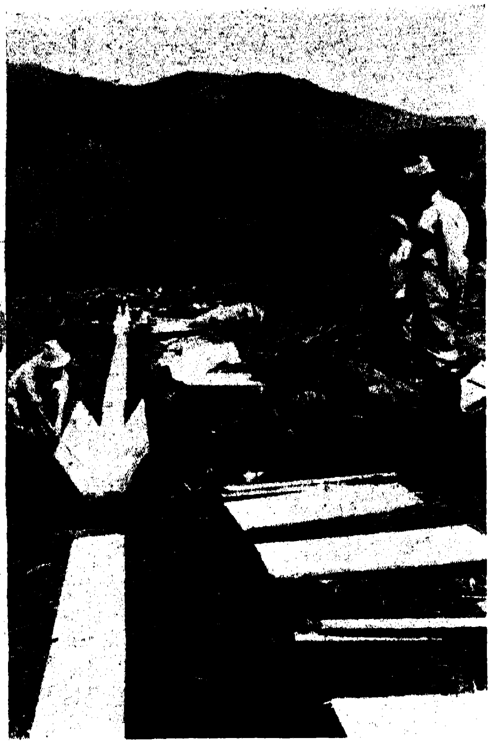

Fig. 15. Precast concrete slabs for ditch lining — Wailuku Sugar Company. These slabs, carrying interior reinforcing of poultry wire, are light and easily laid. They increase the carrying capacity of the ditch and protect it from erosion.

Fig. 16. Backfilling around a precast slab ditch—Wailuku Sugar Company. The template holds the loosely placed slabs to the required cross section while dirt is tamped behind them.

Fig. 17. A precast slab ditch in operation —Wailuku Sugar Company. The iron structure in the foreground permits the delivery of part of the water into level ditches on either side without excessive disturbance to the lines of flow. Here the water had a velocity of 20 feet per second.

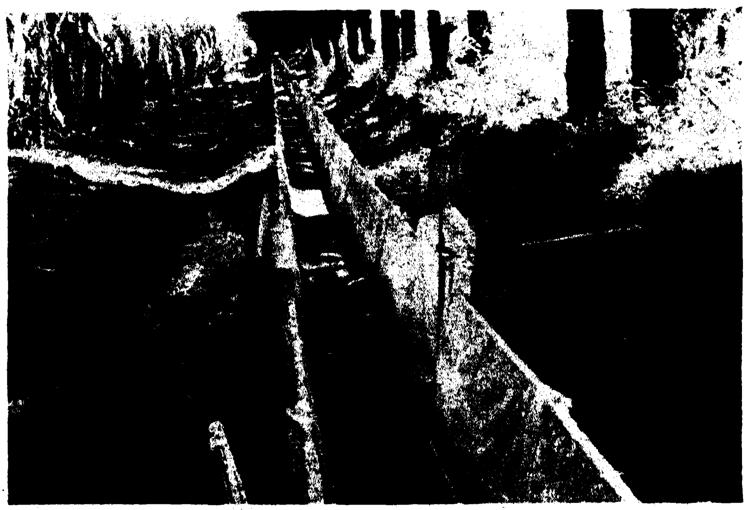

Fig. 18. Precast concrete slab ditch—Kohala Sugar Company. The iron gate fitting into the bottom of the section is similar to that shown in use in Fig. 17. Gates of this type permit the removal of a part of the total amount in the flume with a minimum of splash.

But even with this qualification some trends are to be noted. Apparently field ditches have received more attention than main canals during the period. The length of lined field ditches increased 250 per cent while lined main canals were increased by 17 per cent. It is undoubtedly true that the main canal systems are more completely lined than the field ditches and have consequently needed less attention.

The favored materials in lining main canals have been concrete, cast in place, and cut stone. A significant decrease in the main ditches lined with precast concrete slabs and cement plaster is to be noted. Concrete cast in place and cut stone have also been popular in lining field ditches but with smaller ditches the cement plaster linings have been of greatest use. The length of field ditches lined with this material has increased almost fourfold since 1932.

Of note too, in the survey of trends is the increasing use of concrete pipe in field ditches. More than 100,000 feet of this material is noted in 1937. Practically none of this material was reported in similar service in 1932.

Modern precast concrete slabs, carrying reinforcing poultry wire, shown in Figs. 15-18, have also been widely used in field ditch-lining programs, particularly at Wailuku Sugar Company.

Trends in Land Reclamation:

Although not land reclamation in the sense that arid lands are provided with irrigation facilities or swamp lands freed from salts and surplus water, mention should be made of the modern trend of improving land by the careful trapping of sediment in freshet flows. At Ewa Plantation Company and at Kekaha Sugar Company intricate flood canals are provided so that occasional freshet waters charged with valuable sediments may be led into great stilling basins where the sediment is dropped. Considerable valuable cane land has been added to the cropped area at Ewa Plantation Company during recent years by this procedure. At Kekaha Sugar Company flood ditches are carefully cleaned prior to the season during which freshets may be expected in order that a high velocity within the stream may keep the silt in suspension until the proper point for deposition is reached.

At Ewa Plantation Company reservoir sediments are used toward the same end. The workman shown in Fig. 19, working with a fire hose connected to a portable, gas-driven pump, is washing out the sediments which have collected in the reservoir during 30 years of constant use. The drainage water heavily charged with this sediment is carried to the thin soils of the coral fields or to others where a top dressing of good soil would be of value. The additional benefit resulting from increasing the capacity of the reservoir is evident.

Water-Measuring Programs:

Without consideration of the details of the water-measuring equipment of the plantations as given in Table III, it is possible to note the trends in local practice. Outstanding is the increasing popularity and use of the Parshall flume. First introduced in 1927, the use of this device has increased regularly. The decrease in the use of weirs of various types and submerged orifices is largely accounted for by the substitution of Parshall flumes. The use of Parshall flumes practically doubled in

Fig. 19. Reservoir cleaning with a high pressure water jet—Ewa Plantation Company. In addition to increasing the capacity of the reservoir this practice permits the building up of thin soils on the coral fields.

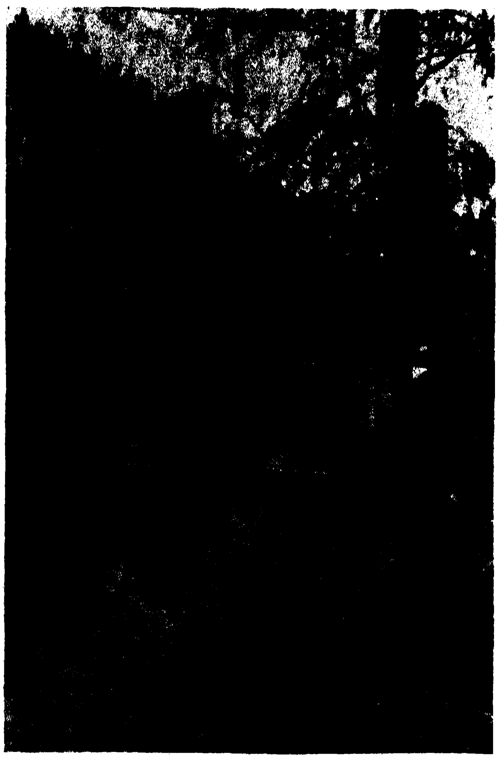

Fig. 20. A concrete Parshall flume—Grove Farm Company. The Parshall flume, either of concrete or wood, is rapidly becoming the standard water-measuring device on Hawaiian Plantations. Four hundred of them are now in use.

the five-year period since the last census. Four hundred flumes, 337 of them being of concrete, were reported in 1937. A typical Parshall flume installation is shown in Fig. 20.

Since the Parshall flume gives only an instantaneous rate of flow, some form of water-stage register is required for an accurate determination of total quantity. In this field various models of the Stevens water-stage register have had almost universal acceptance on Hawaiian plantations.

TABLE III

Water-Measuring Devices in Use on Hawaiian Sugar Plantations, September 1, 1937

Type of Device	Hawaii	Kauai	Maui	Oahu	Total 1937	Total 1932	% change based on 1932 return Increase	Decrease
Weirs								
Rectangular	31	42	21	26	120	217	..	44
Triangular	..	..	..	..	..	6	..	..
Submerged Orifices	..	..	..	..	..	664	..	..
Fixed Area	..	..	1	119	120	..	..	70
Adjustable Area	..	..	..	73	73	..	..	..
Rated Sections	2	23	23	7	55	61	..	10
Parshall Flumes								
Wood	2	12	40	10	64	60	7	..
Concrete	12	25	234	70	341	108	210	..
Venturi Meters	1	5	26	57	89	70	27	..
Integrating Devices								
Great Western	..	..	..	163	163	422	..	61
Reliance	..	..	..	39	39	39	..	..
Pipe Line	..	4	..	18	22	..	..	..
Water-Stage Registers								
Stevens	8	43	75	53	179	170	5	..
Friez	..	..	16	2	18	20	..	10
Gurley	10	5	..	17	32	36	..	11
H.S.P.A.	6	..	4	24	34	..	..	..
Brown	..	..	10	..	10	12	..	17

It should be noted that the Venturi meter holds its preeminent position as a measuring device in pipe installations particularly on pump discharge lines.

Trends in Water and Labor Economy:

Since 1931 the increasing use of the newer methods of irrigation has naturally resulted in the accumulation of considerable information with respect to their value in water and labor administration. On Maui, for example, where more than half of the irrigated acreage is served by some form of long-line or border method, such large areas are available for comparison that some confidence may be placed in the results. Table IV* gives the results of such comparisons. The figures are self-explanatory. It should be mentioned, however, that the areas involved in the long-line and border summations involve a greater percentage of plant and young ratoon crops than is the case with contour lines.

* Condensed from data supplied by F. W. Broadbent, Hawaiian Commercial and Sugar Company.

TABLE IV

Comparative economies in water and irrigation labor as related to irrigation methods on Maui Plantations

Method	Plantation	Acres irrigated per Man-Day	Yield, Tons per Acre		Acre-inches Irrigation water per			Acres involved in Averages
			Cane	Sugar	Acre	Ton Cane	Ton Sugar	
Contour Lines	Pioneer Mill Co.	1.3	85.7	9.87	283.7	3.31	28.7	666.4
	Wailuku Sugar Co.	2.4	45.4	6.00	232.5	5.12	38.7	14.2
	Maui Agr. Co.	1.5	80.9	11.53	223.8	2.76	19.4	293.4
	Hawn. Com. & Sugar Co.	1.5	79.7	11.50	279.5	3.50	24.3	999.9
	Average or Total	1.7	72.9	9.72	254.9	3.67	27.8	1,973.9
Long Lines	Pioneer Mill Co.	4.9	76.0	8.08	243.9	3.21	30.2	277.6
	Wailuku Sugar Co.	5.1	68.7	6.90	138.4	2.01	20.0	166.1
	Maui Agr. Co.	4.6	84.9	10.50	206.1	2.43	19.6	241.2
	Hawn. Com. & Sugar Co.	3.6	92.7	13.34	316.9	3.42	23.7	1,535.2
	Average or Total	4.5	80.6	9.70	226.3	2.77	23.4	2,220.1
Border	Pioneer Mill Co.	7.7	92.7	9.97	268.1	2.89	26.9	585.1
	Wailuku Sugar Co.	7.7	64.4	7.65	123.0	1.91	14.8	134.3
	Maui Agr. Co.	4.7	89.3	12.40	204.7	2.29	16.5	49.4
	Hawn. Com. & Sugar Co.	6.1	87.1	13.01	252.2	2.89	19.3	1,084.9
	Average or Total	6.5	83.4	10.8	212.0	2.50	19.4	1,853.7

More direct evidence of the interrelation between the adoption of the newer methods of irrigation and the irrigation labor requirements is provided in Table V and in the first eight columns of Table VI. In each of the plantations reported the spread of the newer methods has been reflected in a significantly reduced labor expenditure in irrigation.

TABLE V

Labor utilization as related to the adoption of the newer methods of irrigation.
Hawaiian Commercial and Sugar Company

Crop	Acres Irrigated	Per cent of Area in Newer Systems	Man-Days Irrigating Per Ton Cane	Man-Days Irrigating Per Ton Sugar	Man-Days Irrigating Per Acre
1931	7,863	0	0.42	3.0	29
1932	7,726	0	0.41	2.9	31
1933	7,843	7.2	0.33	2.2	24
1934	7,905	17.1	0.31	2.1	22
1935	6,714	32.9	0.27	1.8	21
1936	6,572	45.6	0.23	1.6	20

TABLE VI

Labor utilization as related to the adoption of the newer methods of irrigation.
Ewa Plantation Company

Year	Acres Irrigated	Per cent of Area in Newer Systems L-L	Per cent of Area in Newer Systems Border	Man-Days Irrigating Per ton Cane	Man-Days Irrigating Per ton Sugar	Man-Days Irrigating Per Acre	Man-Days Per Acre for all other operations*	Total Man-Days Per Acre for Year
					Annual Basis			
1931	7,991	1.1	8.8	.20	1.61	19.6	49.9	69.5
1932	8,169	1.3	30.0	.17	1.35	17.4	49.0	66.4
1933	8,422	1.7	45.6	.14	1.05	13.2	46.3	59.5
1934	8,348	2.3	56.7	.10	.75	8.8	45.3	54.1
1935	8,043	2.3	68.2	.07	.57	6.4	43.3	49.7
1936	8 354	5.3	70.6	.09	.70	7.1	43.1	50.2
					Crop Basis			
1934	8,348	2.3	56.7	.16	1.25	14.7	44.9	59.7
1935	8,043	2.3	68.2	.10	.83	9.3	45.0	54.3
1936	8,354	5.3	70.6	.08	.66	6.5	39.6	46.2

* Including planting, weeding, fertilizing, and harvesting.

It seems evident from Table IV and the more detailed figures from Tables V and VI that the newer methods have lived up to their early promise with respect to their economy of labor in water distribution. It is also clear that this economy has been accompanied with significant decreases in the amount of water required for the production of a ton of cane or a ton of sugar. Moreover the average yields in both cane and sugar have increased with the adoption of the newer methods although closer scrutiny indicates that this is not always true when the plantations are considered individually, nor is it necessarily true that this increase has been brought about entirely by the modification in irrigation methods.

Such comparisons of the labor involved in irrigating, leading as they do to expression in some such unit as acres irrigated per man-day, are confusing and may be misleading in the long run. Irrigation by the old contour-line method was a slow procedure, as the figures indicate. Only a limited amount of water could be delivered to the individual irrigator and while that small flow was running into the lines, there was opportunity for such a necessary operation as weeding.

With more modern methods the tempo of irrigation has been stepped up. Increasing the area that a man may irrigate from 1.7 acres per day to perhaps four times that area, as indicated by the experiences on Maui, must be at the sacrifice of such opportunity for weeding. Although the labor, actually charged to irrigation, has decreased significantly with the adoption of faster irrigation procedures it would appear that other labor charges should appear if the fields are to be maintained in their usual condition.

The period characterized by such modifications in irrigation practice has seen great advances toward the end of cheap and expeditious weed eradication. Mechanical cultivators powered either by animals or light tractors, as well as devices permitting the inexpensive handling of chemical sprays, have so reduced the labor cost of weed control that it becomes impossible to note the effect of the additional weeding, which may be necessary with modern irrigation methods, in the annual labor charges for cultivation.

Regardless of how such charges are distributed it seems evident from the last two columns of Table VI that the adoption of new methods of irrigation and the perfection of cultivation procedures have reduced the total labor cost in growing an acre of sugar cane.

At Ewa Plantation Company, the effort required to irrigate an acre of cane, on the annual basis, decreased from 19.6 man-days in 1931 to 7.1 man-days in 1936, or a decrease of 64 per cent. During the same period and with the same limitation, the total labor per acre decreased from 69.5 man-days to 50.2 man-days or a reduction of 28 per cent. The labor benefits of the newer irrigation methods are evident although figures for man-days spent in irrigating may apparently be misleading if used alone.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD JUNE 16, 1937 TO SEPTEMBER 15, 1937

Date	Per Pound	Per Ton	Remarks
June 16, 1937 .	3.455¢	$69.10	Puerto Ricos, 3.45; Philippines, 3.45; Cubas, 3.46.
" 17	3.45	69.00	Philippines.
" 18	3.455	69.10	Philippines, 3.45; Puerto Ricos, 3.45; Cubas, 3.46.
" 24	3.45	69.00	Philippines; Puerto Ricos.
July 1	3.485	69.70	Puerto Ricos, 3.47; 3.50.
" 2	3.505	70.10	Philippines, 3.50; Puerto Ricos, 3.50; Cubas, 3.50; 3.51.
" 8	3.51	70.20	Cubas.
" 19	3.42	68.40	Cubas or Duty Frees.
" 27	3.45	69.00	Philippines.
" 28	3.4867	69.73	Virgin Islands, 3.45; Philippines, 3.50; Cubas, 3.51.
" 29	3.50	70.00	Philippines.
Aug. 4	3.53	70.60	Philippines.
" 5	3.50	70.00	Cubas or Duty Frees.
" 11	3.59	71.80	Cubas.
" 13	3.55	71.00	Philippines.
" 17	3.5867	71.73	Philippines, 3.55; Puerto Ricos, 3.60; Cubas, 3.61
" 18	3.605	72.10	Cubas, 3.60; 3.61.
" 26	3.555	71.10	Philippines, 3.55; Cubas, 3.56.
" 27	3.55	71.00	Puerto Ricos.
" 31	3.50	70.00	Philippines.
Sept. 3	3.505	70.10	Philippines, 3.50; Cubas, 3.51.
" 13	3.45	69.00	Philippines.
" 15	3.415	68.30	Philippines, 3.40; Cubas, 3.43.

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(An asterisk preceding a page number indicates that the article is illustrated.)

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